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Groundwater Management Zones for Conjunctive Water Conservation in Hays County and the Hill Country Region of Central Texas

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Groundwater Management Zones for Conjunctive Water Conservation in Hays County and the Hill Country Region of Central Texas

by

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Dedication

For the springs of Central Texas

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Abstract

Groundwater Management Zones for Conjunctive Water Conservation in Hays County and the Hill Country Region of Central Texas

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The University of Texas at Austin, 2018

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This report examines a provision of Texas groundwater law granting authority to Groundwater Conservation Districts (GCDs) to create Groundwater Management Zones (GMZs) to address significant differences in hydrogeological conditions or groundwater use in specific areas of an aquifer. The report considers whether these management zones are effective tools for conserving groundwater in order to preserve surface water flows particularly in the Hays Trinity Groundwater Conservation District and, more generally, in the Hill Country region of Central Texas. It presents two case studies of existing GMZs in Barton Springs Edwards Aquifer Conservation District and Hill Country Underground Water Conservation District and insights from interviews with GCD staff involved in establishing and refining these zones. The report then evaluates how effective the zones would be for protecting the Middle Trinity Aquifer in the area around Jacob's Well Spring and the Cypress Creek Watershed. It concludes by providing a road map and recommendations based on best practices drawn from the findings described above.

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Chapter 1: Introduction, Context, and Background

Among the many challenges facing communities across the globe is maintaining sustainable access to clean, safe drinking water as the world population continues to climb with global temperatures. Groundwater, under especially intense pressure as the most extracted natural resource in the world, represents 99 percent of the useable water on the planet and is essential to supporting our ecosystems.[1] Some areas of the world and the U.S. have made carefully regulating groundwater a top priority. Unfortunately, Texas is not one of those places as the legislature has repeatedly refused to take such comprehensive action to protect the state's water resources. Given that lack of political will, this report considers existing mechanisms within the state's water regulatory regime that might yet move us towards more sustainable water management policies and practices.

With a rapidly expanding population placing extreme pressure on limited water resources, Texas's current system of groundwater regulation–operating separately from surface water regulation for the most part–will not be sufficient to protect groundwater resources adequate to meet the needs of the state's residents, ecosystems, and industries in the next few decades. The state's complicated and underfunded system of Groundwater Control Districts (GCDs)[2] and Groundwater Management Areas (GMAs)[3]—combined with a host of separate surface water management entities—lacks

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[1] National Groundwater Association, "National Groundwater," National Groundwater Awareness Week.
[2] A GCD is a local governmental entity created by the State Legislature and ratified through local elections in order to manage and conserve groundwater by permitting and regulating groundwater production. GCDs are most often defined by political boundaries such as county lines, so that many GCDs are responsible for managing groundwater from the same aquifer. In order to address problems stemming from widely varying management strategies among GCDs, the legislature created Groundwater Management Areas (GMAs).
[3] A GMA is a regional groundwater planning entity responsible for coordinating GCD planning at the regional, usually aquifer-scale, level. Representatives from each GCD in the GMA help to quantify the amount of groundwater available for production, determine an acceptable level of aquifer drawdown

the kind of coordinated strategies and regulatory powers needed to effectively regulate this common pool resource in a sustainable fashion.[4]

Although the state has moved toward more coordinated aquifer- and regional-level water planning with the creation of GMAs, the Texas Water Code[5] that guides the planning and policy-setting process is structured in such a way that it cannot respond nimbly to the mounting threats of climate change and population growth. Desired Future Conditions (DFCs) are often set, with guidance from Texas Water Development Board (TWDB), for an entire aquifer or at least the portion of it within the GMA.[6] These DFCs, based on large aquifer-wide models, produce inexact estimates that do not adequately account for hydrogeological differences between areas of an aquifer in different GCD jurisdictions. While setting a DFC for and entire aquifer or large region of it provides the "big picture" understanding of groundwater quantity and availability, such DFCs fail to account for varying aquifer depth and well production capacities in different parts of any major aquifer. Based on these general DFCs, the TWDB then creates Groundwater Availability Models (GAMs) that, again, do not adequately account for localized conditions. A recent study comparing GAMS to actual groundwater elevations across the Trinity Aquifer indicated significant discrepancies, notably model overestimations in

(expressed as the Desired Future Condition (DFC)), and plan to manage the groundwater accordingly. All of these entities, their responsibilities, and planning processes will be described in greater detail later in this report.

[4] Dupnik, "A Policy," 1-2.

[5] The Texas Water Code sets out how the legislature has structured the laws governing water management and regulation. The code "is enacted as a part of the state's continuing statutory revision program… [which] contemplates a topic-by-topic revision of the state's general and permanent statute law without substantive change." Texas Water Code §1.001(a).

[6] The Texas Water Development Board is a state agency founded in 1957 with the mission "to provide leadership, information, education, support for planning, financial assistance and outreach for the conservation and responsible development of water for Texas."
Texas Water Development Board. "About the Texas Water Development Board."

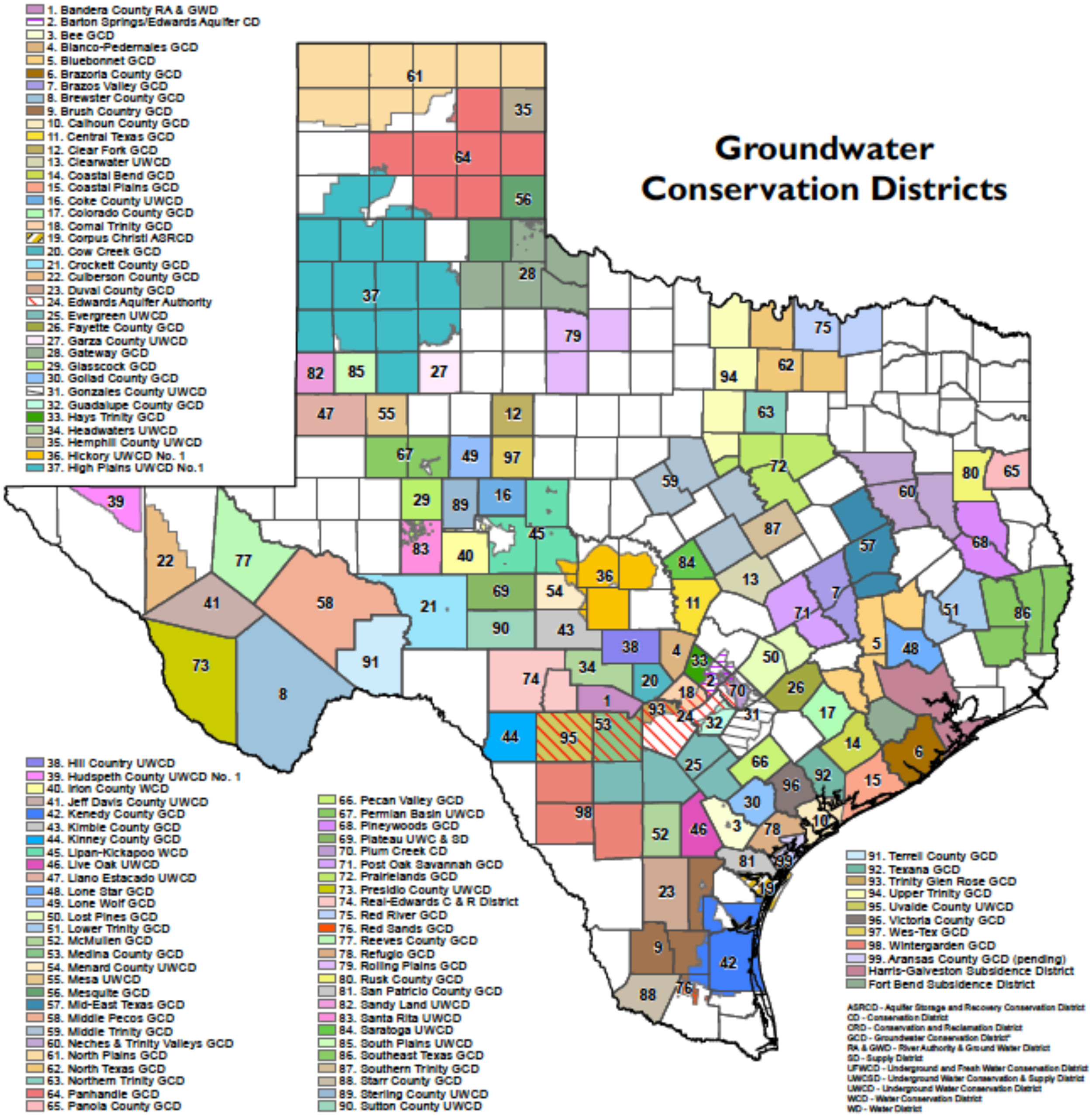

Figure 1: The Texas Water Development Board's (TWDB's) map of GCDs across the state. The white spaces are areas where no GCD has been established.

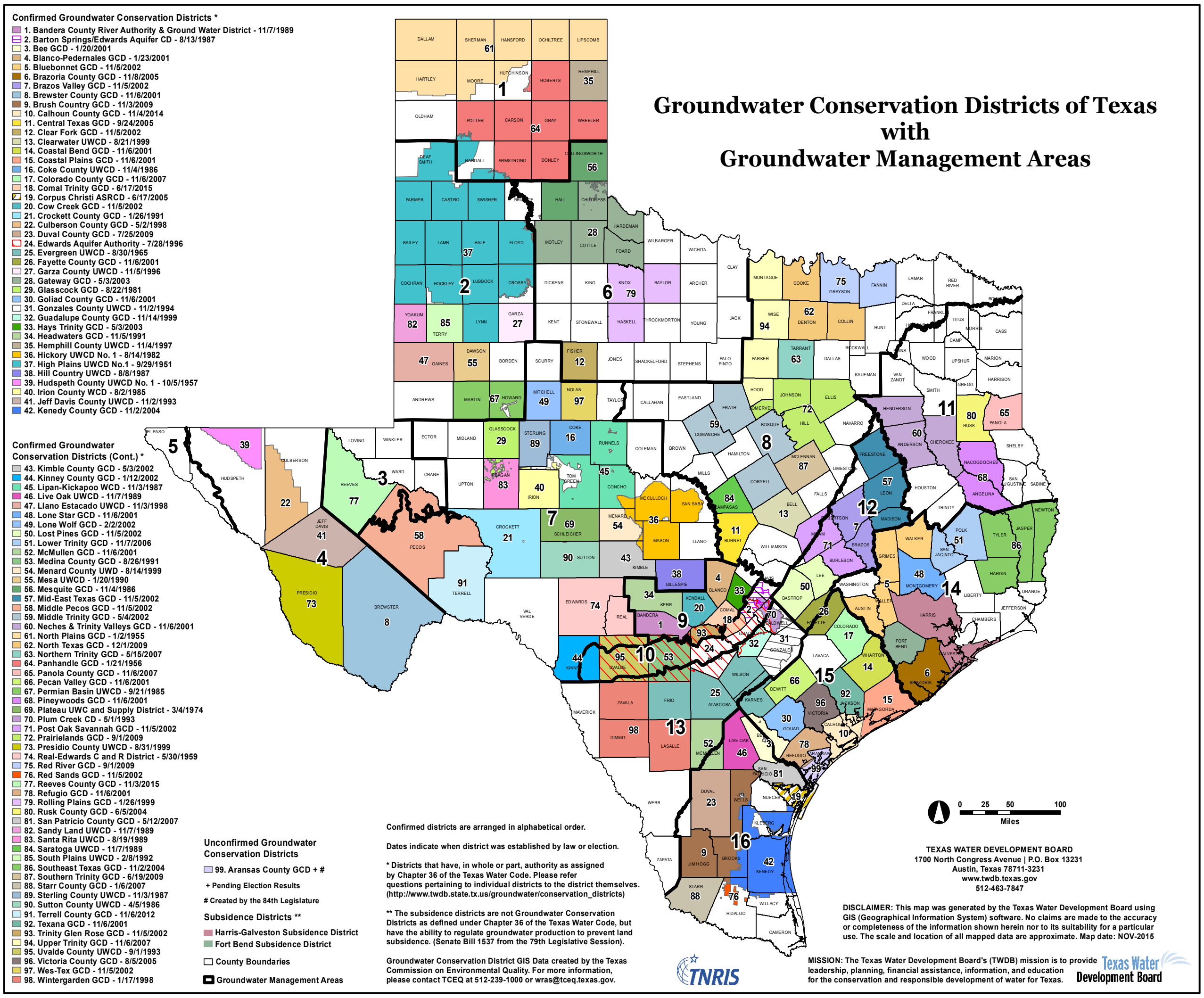

Figure 2: TWDB's map of GCDs grouped into GMAs across the state.

drought years, as well as questionable assumptions about future pumping not varying between wet and drought years.[7]

This report will focus on one existing regulatory tool capable of addressing these problems by dividing hydrologically and geologically distinct areas of an aquifer Groundwater Management Zones (GMZs) with management strategies tailored to their

[7] Groundwater Management Area 9, *Comparison of Groundwater*, 37.

particular characteristics.[8] This report will consider whether GMZs are effective tools for groundwater management currently employed in other GCDs—namely Barton Springs Edwards Aquifer Conservation District (BSEACD) and Hill Country Underground Water Conservation District (HCUWCD)—and whether they will be effective for protecting threatened water resources in the Hays Trinity Groundwater Conservation District (HTGCD), the broader Hill Country region, and elsewhere in the state. Figure 3 shows the location of these neighboring conservation districts.

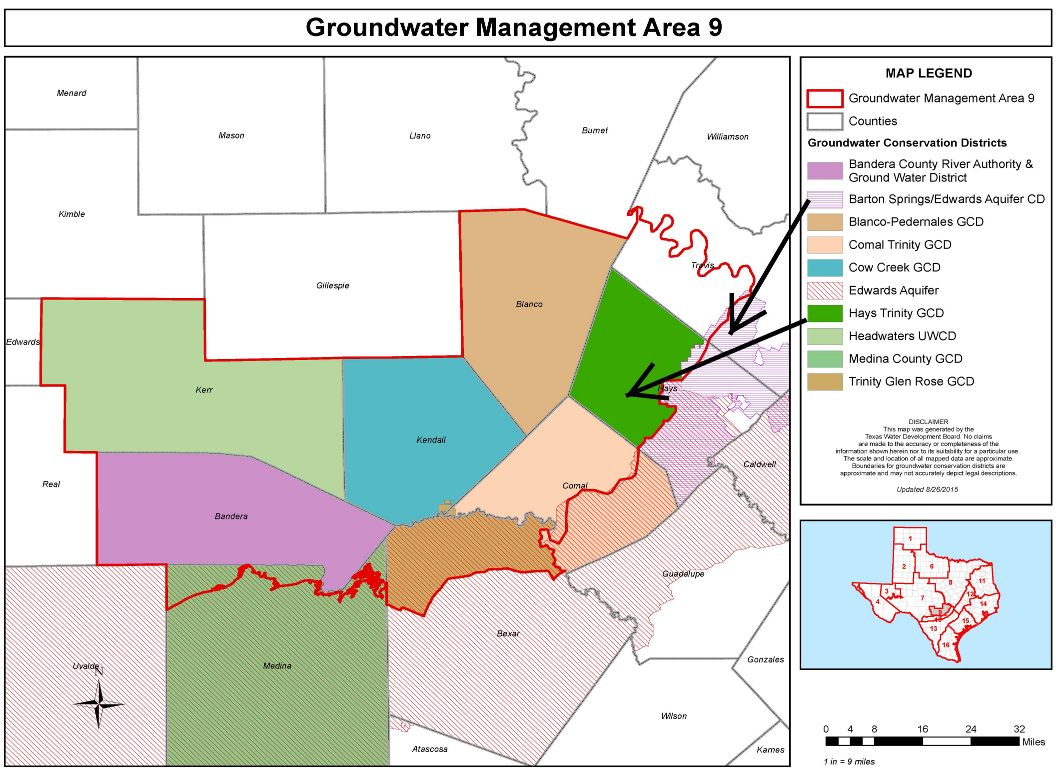

Figure 3: GMA 9 with the GCDs central to this study identified with arrows.

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[8] Texas Water Code § 36.116(d). This subsection of Chapter 36 does not provide a specific name for these areas, so the names for them vary from GCD to GCD. Since BSEACD is the primary case study here, I use the term Groundwater Management Zone to refer to management and regulatory strategies created by GCDs using the authority granted by this subsection of the Water Code.

A Groundwater Management Zone (GMZ) provides districts more authority and local control to impose tighter limits on groundwater production than the GMA-defined Desired Future Conditions (DFCs) and resulting MAGs allow. GMZs are established through GCD rule changes, which can provide some protection from the political instability and scientific imprecision. If a GCD determines that areas of the district differ substantially and require different rules, they may define different aquifers, aquifer subdivisions, geological formation, or area containing a combination of those as distinct management zones. While rules such as limiting which types of permits are allowed, well spacing requirements, and production limits can be decided at the GCD level without GMA approval, setting a different DFC requires GMA approval. Once the GMZs are defined in the GCD's rules, they must be considered in the GMA planning process.

Using GMZs, a district can then develop rules and/or different DFCs for those specific zones to protect them from groundwater depletion by tying pumping limits to well levels or even stream and spring flows, the latter allowing a form of conjunctive water management for which there are few tools in Texas.[9] During the recent drought years several plains and western states have adopted such conjunctive water management strategies to mitigate drought and flood cycles, which have resulted in billions of dollars in damage in Texas.[10] Conjunctive water management also "represents one of the most important responses to improving drought water-supply security and for long-term climate-change adaptation."[11] Although regulated in very different ways, surface water and groundwater management must be integrated to face the challenges that lie ahead.

[9] Texas Water Code § 36.116(d). This subsection of Chapter 36 does not provide a specific name for these areas, so the names for them vary from GCD to GCD. Since BSEACD is the primary case study here, I use the term Groundwater Management Zone as they do.
[10] Sugg, Ziaja, and Schlager, "Conjunctive Groundwater," 3.
[11] Foster and van Steenbergen, "Conjunctive Groundwater," 1.

The report will examine and evaluate the potential for GMZs to more effectively regulate groundwater and unique hydrogeological features in Hays County, specifically within the Hays Trinity Groundwater Control District (HTGCD). Establishing GMZs within HTGCD is important for three main reasons: 1. Hays County is one of the fastest growing county in Texas, and they are growing in a suburban sprawl development pattern that puts excessive pressure on water resources;[12] 2. The District covers one of the most sensitive contributing and recharge zones on the Edwards plateau, for both the Trinity and Edwards Aquifers, which millions of residents in the region rely on for drinking water and the natural environment relies on for healthy functioning ecosystems; 3. As a result of its enabling legislation, HTGCD has relatively little authority or ability to raise revenue. A GMZ would allow HTGCD to protect areas such as Jacob's Well Spring and Cypress Creek by placing tighter limits on groundwater production even without setting a different DFC.[13]

Given its unique and highly interactive surface water and groundwater features which support the growing population who rely primarily on groundwater for human use, unique and endangered species which rely on constant spring and creek flows, and the economic importance of water resources in supporting area economies, the District provides a prime location to consider how GMZs might be effective mechanisms—currently available—to protect the Middle Trinity Aquifer to a degree sufficient to

[12] Bixler, Zutz, and Lovell, "It Takes."

[13] Jacob's Well Spring is an artesian spring and extensive underwater karst cave system that forms the headwaters of Cypress Creek in central Hays County, located in Central Texas on the eastern edge of the Edwards Plateau. Jacob's Well is one of the "sacred springs" of the region, which are a part of the region's Native American creation myths and are integral to tribal rituals to this day. The Well's iconic beauty defines the cultural identity of the Wimberley Valley. Its environment, economic, and cultural importance are discussed in greater depth in Chapter 3 of this report.

provide plentiful, clean, affordable water for human use while maintaining environmental water flows needed for a healthy ecology and economy.

In 2010, GMA 9 voted to substantially increase the DFC for the undifferentiated Trinity Aquifer to "Allow for an increase in average drawdown of approximately 30 feet through 2060."[14] However, a recent study of the Middle Trinity Aquifer, which provides most of the groundwater production in Hays County, concludes that the aquifer is "under stress" and declining at a rate such that the Middle Trinity could reach the DFC drawdown set for 2060 by 2040.[15] A GMZ would allow the HTGCD to slow that rate, in sensitive areas of the aquifer prone to depletion, by curtailing permitted pumping under certain aquifer conditions such as monitor well levels or springflow. The latter form of conjunctive water management would be appropriate for the Jacob's Well and Cypress Creek area because of the high degree of interaction between groundwater and surface water along this spring-fed creek. Maintaining a minimum spring flow of 4-7 cubic feet per second (cfs) at Jacob's Well is essential to keeping the wet portion of Cypress Creek below the well flowing and the water quality high enough to support its aquatic wildlife.[16] Although aware of this study and the modeling shortcomings mentioned above, GMA 9's recent joint planning cycle opted to retain the 30 foot drawdown citing the need for further study in non-drought years.[17]

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[14] Texas Water Development Board, *Groundwater Management*, 1.
[15] Hunt and Smith, *Desired Future*, 4.
[16] River Systems Institute, Texas State University-San Marcos, *Cypress Creek*, 119.
[17] Groundwater Management Area 9 Joint Planning Committee, *Groundwater Management*, 32.

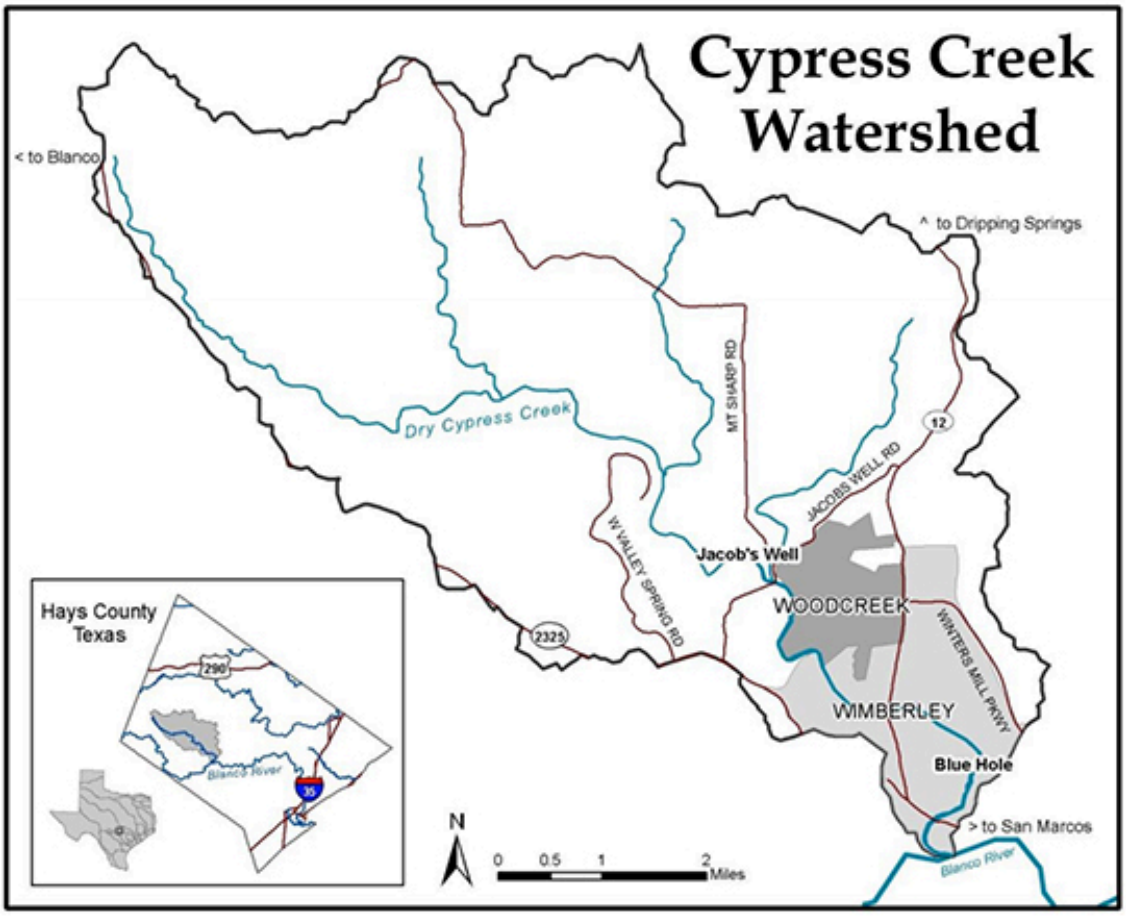

Figure 4: Location of Jacob's Well Spring and the Cypress Creek Watershed.[18]

Given uncertainty about the length and severity of drought conditions, HTGCD could move forward with creating a GMZ for Jacob's Well and Cypress Creek, an especially environmentally and economically vulnerable area of the District. According to the HTGCD's 2016 Groundwater Management Plan, "The District is opposed to planned depletion (mining) of the Trinity Aquifer as a groundwater management policy. The HTGCD reaffirms its goal of sustainable groundwater management based on an

[18] The Meadows Center for Water and the Environment, "Cypress Creek," map.

approved and publically [sic] reviewed DFC."[19] One of the Management Plan's guiding principles is to "Continue to develop groundwater production limits based on scientific study of the aquifer, modeled available groundwater, and a focus on areas/zones of critical depletion."[20] Clearly, creating a GMZ for Jacob's Well and Cypress Creek conforms to HTGCD management policies and principles. Doing so in a timely manner, directly following recent rainy years, would be an effective and forward-thinking initiative to protect this economically, culturally, and environmentally important spring.

BSEACD provides a useful template for HTGCD to develop GMZs and strengthen their ability to regulate sustainably despite an unsustainable DFC through internal rule changes rather than more arduous legislative ones. BSEACD has defined GMZs within its jurisdiction to manage groundwater permitting for six distinct aquifers or aquifer subsections: the Eastern Freshwater Edwards, the Western Freshwater Edwards, the Saline Edwards, the Trinity Outcrop, the Middle Trinity, and the Lower Trinity. Boundaries are defined by both surface area on the ground and subsurface strata to delineate the horizontal and vertical shape of the subaquifer area.[21] These zones provide the district more precise control and regulation of pumpage according to groundwater availability and DFCs calculated to protect hydrological features such as Barton Springs. Once established they may also make BSEACD's conservation efforts more effective especially in the Trinity Aquifer for which both districts issue permits. Establishing a GMZ using BSEACD's approach represents one way among many to implement the authorities granted under this subsection of Chapter 36. HCUWCD uses a

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[19]Hays Trinity Groundwater Conservation District, *Groundwater Management*, 29.
[20] *Id*, 5.
[21] Barton Springs Edwards Aquifer Conservation District, "Permit Types," Barton Springs Edwards Aquifer Conservation District.

distinct approach, one based more on use factors than hydrogeological ones. The differences and their potential pros and cons for HTGCD will be discussed later. These differences underscore the flexibility of the subsection and how adaptable it is to a wide variety of geological and geographical contexts.

To provide further context, Chapter 1 will set forth the methods used in this study. Chapter 2 of this report will begin with a summary overview of groundwater regulation and management in Texas including other less binding provisions for conjunctive water management in the Texas Water Code.[22] Chapter 3 will detail some of the threats specific to groundwater resources in Hays County and the Hill Country Region. Chapter 4 will examine BSEACD's GMZ rules, rulemaking processes, and mechanics to provide a case study of the regulatory scheme in place. This chapter will include GCD staff interview data on how the GMZs function to reach the DFC specific to the Barton Springs segment of the Edwards Aquifer, a DFC tied to maintaining a minimum springflow at Barton Springs. It will also include a smaller case study of HCUWCD's rules and regulations to provide an alternate illustration of how this provision of the Texas Water Code can be interpreted. Chapter 5 will present an evaluation of how and why a GMZ will or will not be an effective tool HTGCD could use to protect Jacob's Well Spring and Cypress Creek based on general criteria for effective management to protect groundwater for human use and environmental flows. Finally, Chapter 6 will offer recommendations for establishing GMZs to maximize effective groundwater protection in the Hill Country Region and across the state.

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[22] Conjunctive water management is the coordinated management of groundwater and surface water. As Cobourn et al point out, "Conjunctive management policies differ widely across states, but they share a common goal–to jointly manage surface and groundwater to maximize the availability and reliability of water supplies for multiple uses." Conjunctive water management is especially important in regions with high surface water and groundwater interaction.
Cobourn, Elbakidze, and Ghosh, "Conjunctive Water," 278.

1.1 Methods: Approach to the Research Question

I approached this research question initially in the context of Texas groundwater policy research with the aim of finding existing regulatory and management tools already a part of state statute. Because the legislature meets only every two years and the political culture in Texas prioritizes private property rights over natural resource regulation, legislative changes imposing stronger regulations are slow to materialize. Given the current threats facing the Hill Country region described Chapter 3, we need use what tools we do have at our disposal now to avert a looming water shortage crisis. My working hypothesis was that GMZs would indeed provide some much needed protection for localized groundwater resources in the region and perhaps elsewhere in the state, but that they would likely be inadequate as durable long-term solutions to groundwater depletion if not part of a regionally coordinated management system.

1.2 Methods Employed and Rationale for Using Them

The methods employed in this report include a brief literature review; extensive archival research into Texas water law as well as a variety of planning and policy documents; case studies of existing GMZs including how they were created and how they function; interviews with professionals with direct knowledge of the creation and function of these management zones; and a presentation of the findings. My literature review focused primarily on Texas groundwater law, the rule of capture, and conjunctive management strategies in order to better understand the difficulties and dangers of the state's bifurcated system of surface water and groundwater management. It was necessary to look closely at Chapter 36 and the state's system of groundwater planning and management to grasp the statutory roots of the problem or, in other words, why exactly it is so difficult to sustainably manage groundwater when it is treated as private property rather than the common pool resource it clearly is. My research led me to strategies for conjunctive management strategies effective in other states prompted research into elements of the Water Code that allowed for, encouraged, or even mandated recognizing the interconnectedness of groundwater and surface water in water and planning and management practice. While several parts of the Chapters 35 and 36 of the Code do acknowledge surface water and groundwater interaction, none that I found offered binding regulatory authority to promote more sustainable conjunctive management except for the subsection that comprises the topic of this report.

Archival research in the form of watershed protection planning, climate, demographic, and economic studies of the area was also necessary to clearly articulate the threats that GMZs are intended to mitigate. Without painting a clear picture of those threats to communicate a sense of urgency, the focus on such a small piece of groundwater law might not make as much sense. Because there exists so little scholarly work specifically focused on §36.116(d) of the Texas Water Code, it became clear that archival research and interviews would be essential to understanding and evaluating GMZs. Policy, planning, and reporting documents from GCDs and other entities paired with the interviews conducted for the study yielded the bulk of the information presented in the findings.

1.3 Study Limitations

Study limitations included the lack of previous scholarship on §36.116(d) of the Texas Water Code mentioned above, the variations in the way the provision is interpreted and applied by GCDs, time constraints in relation to interviews, and limitations on breadth of the study given the depth required to thoroughly investigate the question. While an ample body of scholarship exists on the Rule of Capture and Texas groundwater law vis-à-vis private property, much of that literature is focused on case law, larger reforms, and alternative regulatory regimes employed elsewhere in United States and beyond. Deep dives into statutory language and how those are translated into practice seem to be comparatively rare.

The variations in terms of structuring and naming GMZs from GCD to GCD limited the ability to provide a comprehensive account of GMZs across the state. The law, planning processes, and management and regulatory practices are all complex systems that demand time and patience to fully explain. The science involved in groundwater management, primarily hydrogeology, is equally complex and difficult to communicate. A modicum of understanding in both fields was prerequisite to formulating interview questions that would yield the necessary data to address the research question. Scheduling interview time with often-overburdened GCD staff members limited the amount of data collected. Finally the need to explain in depth how the GMZ systems in the case studies were created and how they function also limited the breadth of GMZ approaches examined in this report.

Chapter 2: Groundwater Regulation and Management in Texas

2.1 The Legal Background of Groundwater Regulation and Management in Texas

2.1.1 The Common Law Rule of Capture

In Texas, groundwater has long been governed by the common law rule of capture, which confers absolute ownership of water underneath an owner's land meaning that "absent malice or willful waste, landowners have the right to take all the water they can capture under their land and do with it what they please."[23] The 1904 *Houston & T.C. Railway v. East* case established the rule of capture and the Texas Supreme Court continues to cite the rule to this day. Texas is one of the only states in the western half of United States that adheres to this common law doctrine for regulating groundwater. Since surface water is considered property of the state of Texas, these conflicting public and private property regimes represent serious obstacles to effective conjunctive surface water and groundwater management and conservation efforts.

Further, even groundwater that directly feeds surface water bodies such as springs is considered private property if the groundwater is captured anywhere—even a few feet—below the surface of a stream or river bed. Thus, "springs, with all their economic, ecological, and social values, receive scant legal protection under the capture rule."[24] Famously, in *Pecos County Water Control & Improvement Dist. No. 1 v. Williams*, the court affirmed the Williams family's right to pump so much groundwater that the historically prodigious Comanche Springs went completely dry.[25]

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[23] Texas Water Development Board, *100 Years*, 1.
[24] Kaiser, Texas Water Law and Organizations, 35.
[25] Leurig, "From Hell," Our Desired Future.

Figure 5: Comanche Springs in 2013, Photo by Sharlene Leurig.

The rule of capture, also known as the law of the biggest pump, is particularly harmful for karst regions like the Texas Hill Country whose iconic springs and spring-fed creeks define its character, provide increasingly scarce wildlife habitat, and support local economies through recreational activities, tourism, and other forms of economic development tied to high quality of the region's natural resources.

2.1.2 Groundwater Conservation Districts and the Rule of Capture

Over the past 70 years, a system of local regulatory entities known as Groundwater Control Districts (GCDs) has evolved alongside the rule of capture and imposed some limits on pumping. The 1917 Conservation Amendment opened the way for groundwater regulation by charging the legislature with the duty of preservation and conservation of the state's natural resources.[26] The 1930s and 40s saw several failed legislative attempts to exert state ownership or control of groundwater. Finally, with the authority granted by the Conservation Amendment, the Legislature passed the Groundwater Control District Act of 1949 (GCD Act), which established the current system of regulation rooted in local control. The GCD Act created Chapter 36 of the Texas Water Code, which defines the duties and authorities of the all the GCDs across the state. However, enabling legislation for each district varies widely especially in terms of funding. For example, while some conservation districts are authorized to levy ad valorem taxes and collect pumping fees, others—like HTGCD—rely solely on permitting and connection fees for nonexempt wells. That revenue stream perversely incentivizes issuing permit and connecting more users to municipal water systems to maintain adequate funding for District operations.

The code affirms the private ownership of groundwater, but provides some additional limits on pumping as well as powers to govern well spacing and production.[27] For example, Chapter 36 stipulates that—in areas governed by GCDs—landowners may "drill for and produce groundwater below the surface of real property subject to section (d), without causing waste or malicious drainage of other property or negligently causing subsidence."[28] The statute does not, however, go so far as to hold landowners liable for depleting their neighbors' wells. Therefore, "the existence of a GCD does not eliminate the rule of capture in regulated areas of the state. Rather, regulation overlays the rule and

[26] Tex. Const. Art. XVI, § 59(a).
[27] Tex. Water Code § 36.002(a)(1)-(2); Tex. Water Code § 36.116
[28] Tex. Water Code § 36.002(b)(1).

ideally prevents one landowner from pumping to such an extent that nearby wells are impacted."[29] Intended to protect private property rights and allow for some measure of conservation, Chapter 36 ultimately provides no guarantee that a large industrial or agricultural permit holder will not pump at a rate that will cause nearby wells and springs to run dry. The rule of capture thus prevents smaller landowners from protecting their private property rights. The Williams family still holds the largest single, non-municipal groundwater permit in the state to irrigate their large-scale agricultural operations and nearby Comanche Springs is still a dry hole in the ground.[30] Hence, the law of the biggest pump prevails.

Although the GCD Act provided a check on the absolute ownership of the rule of capture, "It also served to firmly establish a wedge between groundwater and surface water law and management despite the efforts of the Texas Board of Water Engineers to unify the two and the growing understanding of their hydrological interaction since the rule of capture was established."[31] Even though conjunctive water management is an optional groundwater planning and management approach provided for in Chapter 36, the bifurcated system of ownership, regulations, agencies, and entities, makes this approach time consuming, onerous, and often ineffectual at sustainable conservation-oriented groundwater management. Finally, the water code itself expressly allows the very entities that oversee groundwater conservation to regulate "the production of groundwater by… [the method of] managed depletion" of the aquifer(s) under their jurisdiction.[32] In other

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[29] Puig-Williams, "Regulating Unregulated," 87.
[30] Leurig, "From Hell," Our Desired Future.
[31] Dupnik, "A Policy," 6-7. Note: The Texas Board of Water Engineers is now The Texas Water Development Board.
[32] Tex. Water Code § 36.116(2)(E).

words, an entity ostensibly created to conserve groundwater can decide to not conserve groundwater.

Exacerbating the disconnects between groundwater and surface water management is the widespread pattern of GCD formation using political rather than hydrological boundaries—thus introducing hydrological disconnects between GCDs with authority over the same aquifers. For many reasons, including preference for local control and the central role of county governments in the creation of GCDs, over half of the districts in the state are defined by county or subcounty boundaries.[33] Neighboring GCDs, often with very different management strategies and enabling legislation, may be permitting with goals counter to one another. Moreover, about 30 percent of Texas has no GCD to regulate groundwater.[34] This decentralized approach to groundwater regulation and management—although it provides flexibility to set policies in accordance with local demographic, geological, and economic contexts—slices and dices aquifers resulting in less effective conservation efforts and unsustainable management.[35] As environmental scientist and water policy expert Insa Theesfeld maintains:

> In order to achieve the successful implementation of decentralized water resource management, the institutional arrangements have to be clearly defined and reasonably well matched with the aquifer system. Poorly defined boundaries may impair collective decision-making by including actors or communities who are not actually stakeholders in the particular resource system, or excluding others who have a stake (Ostrom 1990); *both lead to prohibitively high coordination costs in terms of time and funds* [my emphasis].[36]

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[33] Dupnik, "A Policy," 28.
[34] Puig-Williams, "Regulating Unregulated," 85.
[35] While this report focuses on the value of being able to manage distinct sub-aquifer areas, regional coordination based on hydrological connections within and between aquifers is of equal importance for effective water planning and management.
[36] Theesfeld, "Institutional Challenges," 131-142.

Over the past two decades, the Legislature has sought to remedy this situation by encouraging and later requiring GCDs to coordinate water planning within GMAs. However, these legislative mandates are seldom accompanied by the resources necessary to carry them out in an efficient and thorough manner.[37] The shift toward planning at the aquifer scale attempted to address these problems but has been fraught with unintended consequences, even greater burdens on individual GCDs, and in some cases less successful management outcomes such as unmitigated aquifer depletion.

2.1.3 Groundwater Management Areas and Regional Water Planning

In 1995 the Texas Legislature amended the Texas Water Code to define the creation and functions of Groundwater Management Areas (GMAs) in order to encourage coordinated water management planning among GCDs with the stated aim of protecting "groundwater reservoirs and their subdivisions."[38] The Texas Water Development Board (TWDB) was charged with delineating what would, by 2002, become the 16 GMAs across the state. Recognizing the importance of coordinated planning over aquifers shared by multiple GCDs, chapter 35 of the Texas Water Code requires that to the "extent feasible, the groundwater management area shall coincide with the boundaries of a groundwater reservoir or a subdivision of a groundwater reservoir."[39] Each GMA Joint Planning Committee is made up of staff or board representatives from every GCD within the GMA. For example GMA 9 is made up of 9 GCDs, including the Hays Trinity GCD, and representatives from all 9 GCDs serve on the Joint Planning Committee.

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[37] Dupnik, "A Policy," 81-83.
[38] Tex. Water Code § 35.001.
[39] Tex. Water Code § 35.004(a).

The Joint Planning Committee is responsible for setting Desired Future Conditions (DFCs), which determine a specific amount of aquifer drawdown deemed acceptable or “desired” by GMA consensus. DFCs are defined as “the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times.”[40] With the help of technical advisors, GCD voting members set DFCs based in part on science in the form of Groundwater Availability Models (GAMs) provided by TWDB. Groundwater availability modeling is defined by the agency as “the process of developing and using computer programs to estimate future trends in the amount of water available in an aquifer and is based on hydrogeologic principles, actual aquifer measurements, and guidance from persons with interest in the models and the program.”[41] The resulting GAMs “include comprehensive information on each aquifer, such as recharge (amount of water entering the aquifer); geology and how that conveys into the framework of the model; rivers, lakes, and springs; water levels; aquifer properties; and pumping.”[42] These DFCs are then submitted to TWDB and they, in turn, determine the Modeled Available Groundwater (MAGs) based on their analysis of the adopted DFC. The MAGs subsequently inform the GCD management plans, rules, and policy implementation. The GCDs also use monitor wells to track aquifer levels; that data then informs the next DFC setting process. The MAGs also inform regional planning processes that culminate in the statewide water plan.

Rather than comprehensive water management reform, the legislature has continued to amend the code in this piecemeal layer-upon-layer fashion. In 1997 the

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[40] Tex. Administrative Code §35.610(6).

[41] Texas Water Development Board, *Groundwater Availability*.

[42] *Ibid*.

legislature established 16 Regional Water Planning Areas (RWPAs) and Regional Water Planning Groups (RWPGs) in order to foster a "new water planning process based on a 'bottom-up' consensus-driven approach."[43] In a shift toward conjunctive water management, the RWPGs may include representatives from GMAs and River Authorities

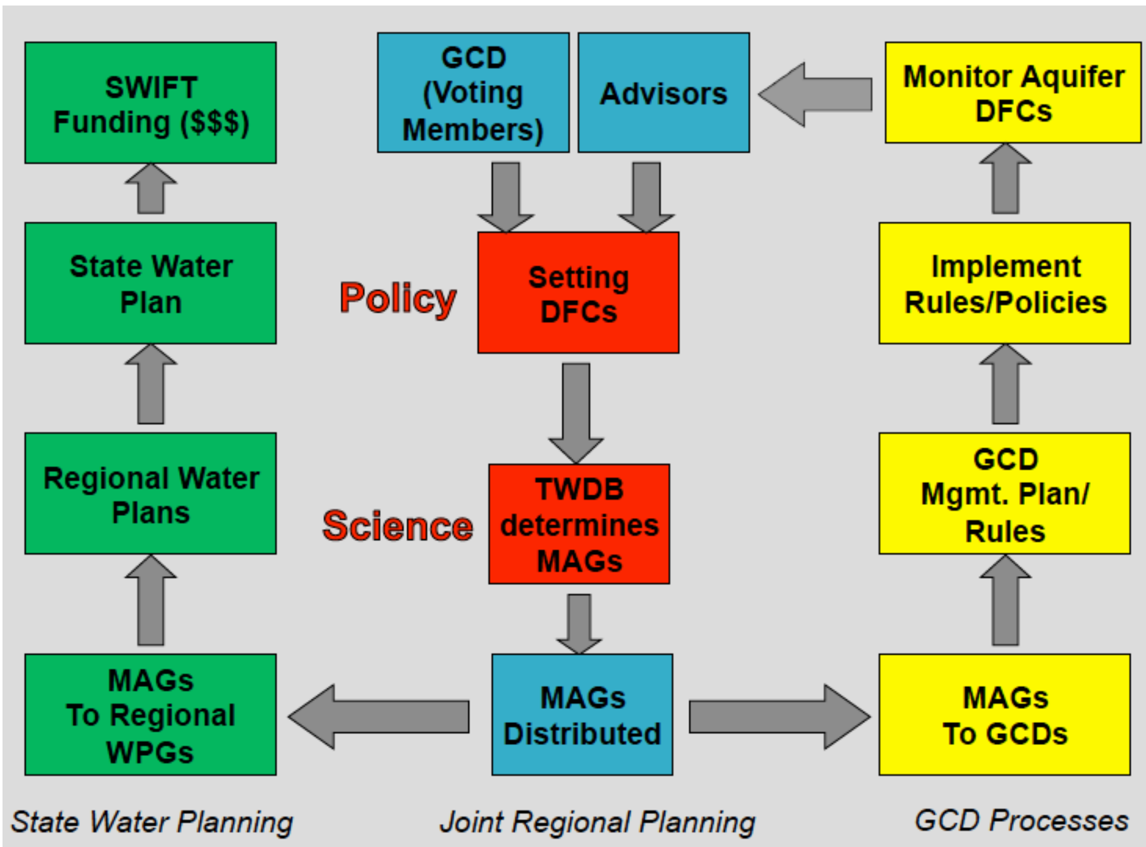

Figure 6: State, regional, and local water planning and regulation flowchart.[44]

so that both surface water and groundwater are considered together in the regional water plans. RWPGs also include representatives from local governments such as municipalities and counties as well as stakeholders from business, industry, environment,

[43] Texas Water Development Board, *Regional Water*.
[44] Dupnik, "Groundwater Management."

agriculture, water utilities, and power generation.[45] Each RWPA plans in accordance with the MAGs derived from the DFCs set by the GMAs within each of the planning regions. Although there are 16 planning areas and 16 GMAs, their boundaries do not coincide. RWPAs vary substantially in size and often cross the boundaries of several GMAs. Likewise, GMAs often include portions of several RWPAs. For example GMA 9 contains portions of Regions J, K, and L; these layers of water planning and management make the processes, especially when consensus is required, more complicated and burdensome for individual GCDs.

Former TWDB Chairman, Bech Bruun, recently praised the two decades of water planning and the four resulting state water plans as true "Texas success story" pointing to, among other aspects of the process, the new "emphasis on constraint-based, numerical water planning using the best available, actionable information" resulting in more responsible planning within the state's water resource limits.[46] Even though the 2017 plan is the result of "the first planning cycle in which modeled available groundwater volumes are the primary basis for groundwater availability statewide," GMA planners are still required to consider a host of other factors, including feasibility given population and economic circumstances, so that the process of setting DFCs is driven by considerations other than scientific data on water quantity.[47] Additionally, GMA groundwater planning—unlike their counterpart RWPGs—is one of the many unfunded mandates in the state's water regulatory system.[48] Already strapped GCDs often lack the resources to develop the science and monitoring necessary to improve the DFC setting process at the

[45] Texas Water Development Board, Regional Water.
[46] Bruun, "Commentary: The Regional," 6.
[47] Texas Water Development Board, *Water for Texas*, 30.
[48] Dupnik, interview by the author.

pace necessary to effectively conserve groundwater where it is most threatened by population growth and development.

While the new regional layers of water planning gesture toward addressing institutional, legal, and hydrological disconnects, this move towards a regional approach has not put regulatory measures in place to prevent unsustainable and potentially environmentally devastating aquifer depletion under some current DFCs. Despite Bruun's bravado vis-à-vis Texas water planning and management, a newly published report from the Mitchell Foundation—vetted by a team of top scientists, policy experts, resource managers, and conservationists working in the field–opens with a much less sanguine salvo: "The current water management paradigm in Texas does not adequately promote sustainable water management or, quite frankly, place a priority on sustaining the needs of our environment."[49]

2.1.4 Regional Water Planning and Desired Future Conditions

As the foregoing discussion indicates, the system by which DFCs and MAGs are determined does not adequately protect or conserve groundwater in a sustainable way. The core problems might be best understood in two interrelated categories, broadly speaking: 1. The body of law governing groundwater regulation and 2. The lack of accurate data about groundwater quantity and flow patterns determined by complex hydrogeological factors, especially the karst regions of Central Texas, which are notoriously difficult to model if not fully understand. The former introduces so many competing considerations in the water planning and permitting process that effective conservation-oriented management becomes voluntary and highly dependent on individual GCDs' powers and political priorities. The latter introduces uncertainty about

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[49] Cardone and Howe, *Advancing One Water*, 4.

the actual quantities of groundwater, where those exist, and how they are dispersed between aquifers and different subaquifer or groundwater reservoir areas. The two are related via the legislature which authors enabling legislation as well as the water code and appropriates money for regulatory agencies and entities to fund the necessary science.

As previously mentioned, the code governing the DFC setting process is watered down with numerous competing considerations so that conserving groundwater to protect surface water flows is far from guaranteed. For example, while Chapter 36 "requires GCDs to consider impacts to springflow when adopting DFCs," it does not require them to protect that springflow.[50] On the permitting side, Chapter 36 requires GCDs to consider "the proposed use of water unreasonably affects existing groundwater and surface water resources."[51] But most GCDs lack the resources and tools to do so in a comprehensive manner.

Even though the districts may adopt different DFCs than the GMA to which they belong, Chapter 36 instructs them to "issue permits up to the point the total volume of exempt and permitted groundwater production will achieve an applicable desired future condition."[52] Since the TWDB uses the districts' DFCs to determine the MAG, GCDs are "required to permit, to the extent possible, up to the managed available groundwater value."[53] While proponents point out that this requirement provides a de facto cap, where previously there was not one, critics argue that permitting up to that amount essentially encourages aquifer mining.[54] Because, apart from the Edwards Aquifer Authority, there is

[50] Puig-Williams, "Regulating Unregulated, 94.
[51] Tex. Water Code 36.113(d)(2).
[52] Tex. Water Code § 36.1132(a).
[53] Texas Water Development Board, *A Streetcar*, 5.
[54] Welles, "Toward a Management," 492. Aquifer mining occurs when more the rate of groundwater extraction from an aquifer exceeds its recharge.

no requirement that DFCs and MAGs must preserve environmental flows,[55] the law provides no effective limits on groundwater mining.[56] DFCs that allow for declining water levels in aquifers are in effect using the "managed depletion" framework. GMA 9 illustrates this problem with its 30-foot drawdown. While that level of groundwater production may be sustainable for some portions of the Middle Trinity Aquifer, recent research has shown that Jacob's Well and Cypress Creek will cease flowing if the aquifer level drops just 2 to 3 feet in the portion of the aquifer in the vicinity of the spring.[57]

The GAMs developed by TWDB are not designed to capture differing conditions, such as depth or amount of possible groundwater production, in different areas of an aquifer. In a 2014 study of GMA 9 GAMs, Hutchison and Beach found, GMA members and opponents of the drawdown had already pointed out that averaging estimated drawdown based on model results for the entire GMA was problematic as it couldn't account for local differences and provided no guidance for comparing local monitoring data with broadly averaged model estimates.[58] Their critique suggests the need for ways to incorporate more localized modeling and data into regional DFC setting processes. Compounding the "heavily averaged model results" across the GMA, the models also make questionable assumptions about pumping volumes remaining the same in dry and wet years. Add to these uncertainties, that even in areas with conservation-minded GCDs, smaller private or "exempt" wells are generally not monitored at all. This gap in pumping

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55 "Environmental Flows express the quantity, quality and timing of water that are necessary to sustain a river, wetland or coastal zone and the associated fish and wildlife."
Meadows Center for Water and the Environment, *Environmental Flows*.

56 The Edwards Aquifer Authority, the result of federal endangered species litigation, is a unique groundwater entity with more regulatory powers and resources than any GCD in Texas.

57 Wierman, *Water Level*.

58 Groundwater Management Area 9, Comparison of Groundwater, 7-8.

data introduces further uncertainty about how much water is actually being pumped annually and therefore if the GMA's management plan will achieve the DFC.

While it makes sense to take multiple factors into to consideration in any complex planning process, when it comes to protecting *finite* common pool natural resources such as groundwater, accurate data on quantity is the only sensible basis for sustainable management. While the TWDB models are a move in that direction in that they incorporate actual monitoring data, they remain models that rely on many generalized assumptions. And as the all too familiar saying goes, you can't manage what you don't measure. Water policy expert Charles Porter makes a similar case for more accurate monitoring data:

> We've got to make sure first of all that we've got a good scientific basis for how much water is available, especially in groundwater… The key is spending the money to fully understand the science. The Water Development Board does a very good job about it, but we still have modeled available groundwater… We need to be more exact about how much water is really there. How can you allocate something if you don't know how much exactly you got?[59]

Until the state legislature does allocate that money, GCDs can and do use the measurements currently in place to manage groundwater, for example monitor wells and spring and stream flows. GMZs are designed for that express purpose, because they are based on constant monitoring of indicators such as well levels or springflows.

2.2 THE NEED FOR MORE INTEGRATED CONJUNCTIVE GROUNDWATER MANAGEMENT IN TEXAS

As many scholars, legal experts, and water managers have argued, conjunctive groundwater management strategies are beneficial and, in many cases imperative, in the

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59 Sanchez, "The Q&A."

more arid regions of the western U.S. but especially so where surface water and groundwater connections abound and affect both quantity and quality of the other.[60] It allows for the most efficient and sustainable water production while avoiding enormous costs associated with surface water infrastructure projects.[61] A comprehensive statutory system designed to foster conjunctive water management would likely be the most effective way to protect Central Texas's water resources because it would allow "managers to address legal, economic, and environmental problems that arise from intensive use of hydrologically connected water systems."[62] While the Hill Country's karst geography and booming population are exemplary of these conditions, the state legislature has not signaled a willingness to take on comprehensive groundwater management reform and the courts have consistently deferred to the legislature even while explicitly recognizing the folly of the rule of capture. Current statutory tools that do recognize and encourage conjunctive water planning and regulation—such as the management zone subsection of Chapter 36—should be used until the courts or the legislature act to decisively move away from this unsustainable common law doctrine.

2.2.1 Conjunctive Groundwater Management in Texas: Tools and Roadblocks

Like other Western states, Texas already practices conjunctive groundwater management to some degree, the most common forms being "aquifer storage and recovery (ASR), managed aquifer recharge, and active management of groundwater

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[60] Sugg, Ziaja, and Schlager, "Conjunctive Groundwater," 3.
Foster and van Steenbergen, "Conjunctive Groundwater," 959.
Welles, "Toward a Management," 501.
[61] Blomquist, Schlager, and Heikkila, Common Waters, 657.
[62] Welles, "Toward a Management," 503.

withdrawals to maintain springflows to surface water bodies."[63] The last is of most interest for this report given the specific hydrogeological context and specific threats detailed in the next chapter. Chapter 36's management plan section charges GCDs to coordinate with surface water governing entities to set goals to address conjunctive management, natural resources, and drought conditions "as applicable" in setting DFCs, but those goals are not binding. While not strictly mandated by statute, GCDs can make groundwater withdrawal management a tactical part of their goals to mitigate impacts to surface water. However, in their review, Sugg and coauthors found "little indication in the literature that this requirement is typically translated in practice into conjunctive management in the form of pumping limitations."[64]

In 2011 the legislature amended Chapter 36 to incorporate conjunctive management into the DFC setting process with the charge to consider "other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water."[65] However, that consideration is weighed along with "socioeconomic impacts," "interests and rights in private property," and "any other information relevant" to the specific DFC, effectively making it difficult for districts to prioritize such environmental impacts and embracing conjunctive management as a guiding principle for joint water planning.[66] The code also requires that GCDs develop management goals "addressing conjunctive surface water management issues," among other factors, in their individual district-level management plans.[67] That provision

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[63] Sugg, Ziaja, and Schlager, "Conjunctive Groundwater," 4. Aquifer Storage and Recovery is the practice of injecting water into an aquifer for later use. Managed Aquifer Recharge is the intentional recharge of an aquifer to restore the aquifer and the environmental benefits it provides.
[64] *Id.* 5.
[65] Tex. Water Code § 36.108(d)(4).
[66] Tex. Water Code § 36.108(d)(6-9).
[67] Tex. Water Code § 36.1071(a)(4).

stipulates including estimates of "the annual volume of water that discharges from the aquifer to springs and any surface water bodies."[68] Despite these legislative charges to incorporate surface and groundwater interaction data into the individual and joint planning processes, the state's decentralized and fragmented system of water management still "leaves it vulnerable to capture by local interests that favor unsustainable pumping for short-term economic gain."[69] If that decentralized framework is one of the systems greatest weaknesses, it also may be—conversely—one of its greatest strengths as local control allows for management that can respond to very different and changing geological and geographical conditions.

2.2.2 Groundwater Management Zones per Chapter 36 of The Texas Water Code

While GCDs would eventually lead to a more regional water planning approach with the creation of larger-scale Groundwater Management Areas (GMA) that aimed to foster regional water planning based on geological boundaries of aquifers rather than political boundaries of counties, later amendments to the code also made it possible for more fine-tuned regulation of smaller sub-aquifer areas by designating GMZs. Chapter 36 provides a tool for GCDs to designate different management areas within the district and adopt different rules and Desired Future Conditions (DFCs) for each area:

> (d) For better management of the groundwater resources located in a district or if a district determines that conditions in or use of an aquifer differ substantially from one geographic area of the district to another, the district may adopt different rules for: (1) each aquifer, subdivision of an aquifer, or geologic strata located in whole or in part within the boundaries of the district; or (2) each geographic area overlying an aquifer or subdivision of an aquifer located in whole or in part within the boundaries of the district.[70]

[68] Tex. Water Code § 36.1071(e)(3)(D).
[69] Welles, 493.
[70] Tex. Water Code §36.116(d).

While this change to Chapter 36 has been criticized as a "concession... [with] the potential to allow local politics to seep back into the decision-making" and "further complicate" the GMA regional planning process, it holds the potential to effectively protect surface water and groundwater resources in specific types of hydrogeological contexts.[71] "Such subdivisions," as Dupnik observes, "could have the effect of increasing the likelihood that DFCs in adjacent subdivisions may be incompatible," unless the zones are defined on a scientific basis "such as aquifer subdivisions/sub-basins or hydrologically connected areas."[72] Although the code does require that GCDs regulate groundwater production according to "a method that is appropriate based on the hydrogeological conditions of the aquifer or aquifers in the district," the statute provides no guidance in defining which methods might be "appropriate" to specific "hydrogeological conditions."[73] Given the limited resources of most GCDs, even in the more conservation-oriented districts, developing scientific data to accurately characterize complex hydrogeological conditions and determining what regulatory method fits best creates another challenge for GCDs, a challenge some districts have successfully risen to meet. The BSCEAD, albeit with more resources than many GCDs, has been a leader in the region in developing defensible policies based on scientific studies and monitoring.

[71] Dupnik, "A Policy," 86.
[72] *Id*. 87.
[73] Tex. Water Code §36.116(e).

Chapter 3: Threats to Groundwater in Hays County and the Hill Country Region

3.1 Surface Water and Groundwater Interaction in Hays County and the Hill Country Region

In his book on water rights in Texas, Charles Porter writes that "surface water, diffused surface water, and groundwater are, have been, or will be ultimately in union with one another; water exists in a conjunctive relationship in all three geological containers all the time."[74] Given those ever-present conjunctive relationships, a thoroughgoing system of conjunctive groundwater management is a necessary strategy for conserving groundwater in any area of the world but especially in dry and semiarid regions like many in the western half of Texas. In the Texas Hill Country and other karst regions with a high degree and rate of surface and groundwater interaction, "you cannot pump stored water without impacting surface water and springflow."[75] Given the significant extent of karst geology in the Texas, the GMZ approach to groundwater management could be an effective tool for many GCDs beyond the Hill Country (See Figure 5).

The 9 major and 21 minor aquifers in Texas contain an estimated 16.8 billion acre-feet of water, but only 25 to 75 percent of that water is recoverable given current technology.[76] That range does not take into account the potential, perhaps devastating, environmental and economic repercussions of pumping even at the lower end of that percentage range. Groundwater not only provides water for drinking, industry, energy and agriculture, but it is also an important source of baseflow for surface water bodies such as springs, creek, lakes, and rivers. Baseflow is defined as the amount of surface

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[74] Porter, *Sharing the Common*, 8.
[75] Puig-Williams, "Regulating Unregulated," 94.
[76] Texas Water Development Board, *Texas Aquifers*, 9.

water flow from groundwater discharge. Aquifers that provide significant discharge are referred to as tributary aquifers. Aside from East Texas, the Edwards Plateau—a region famous for its many springs, seeps, and spring-fed creeks—shows the largest baseflow volume in the state.[77]

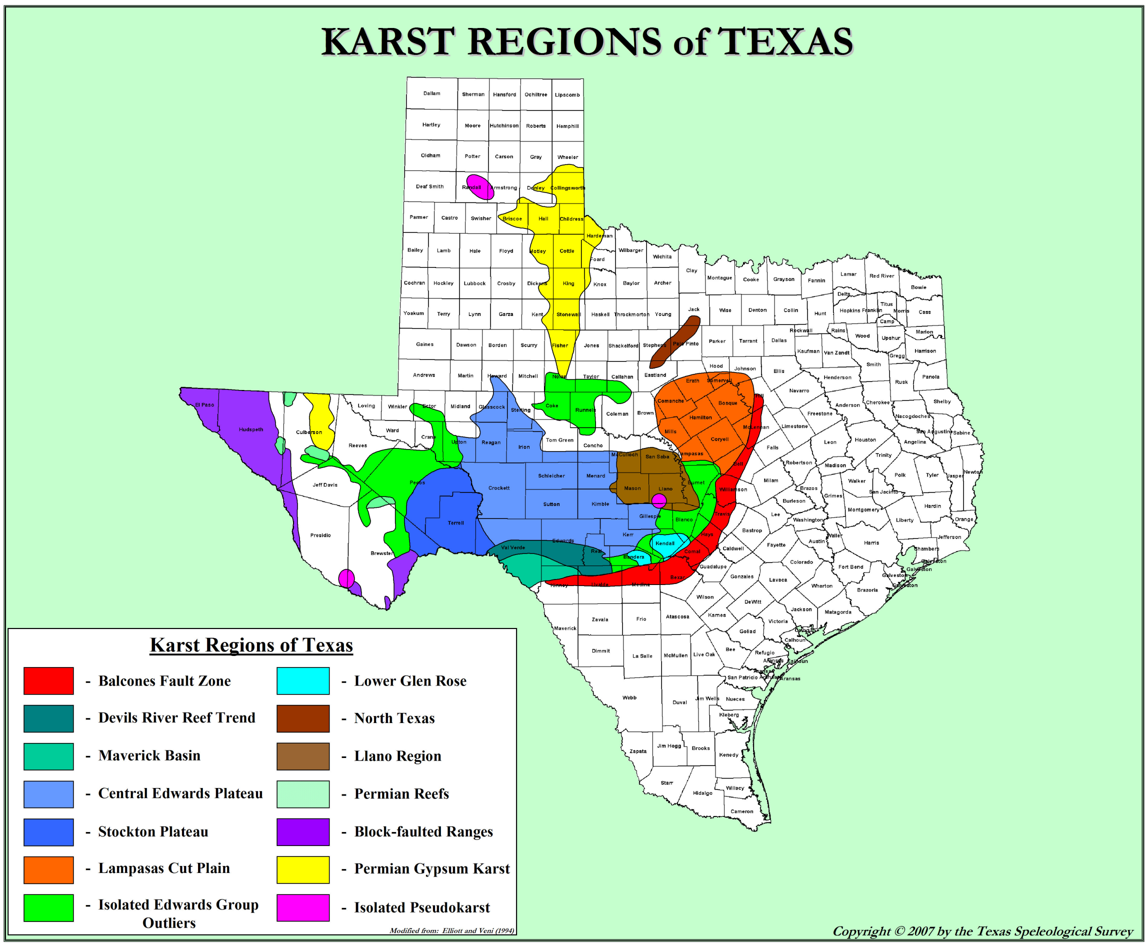

Figure 7: Karst Regions of Texas, from the *Texas Speleological Survey*, 2007.

The Texas Hill Country is home to two major aquifers with high groundwater and surface water interaction, the Edwards in the Balcones Fault Zone (BFZ) and the

[77] Id, 27.

Edwards-Trinity. The BFZ is represented by the red crescent shaped area on the map above (Figure 7). In fact, "The Edwards (Balcones Fault Zone) Aquifer discharges the greatest volume of baseflow per square mile of aquifer area," providing up to 72 percent of streamflow for surface water within its hydrological landscape.[78] Groundwater production in the Edwards Plateau region and along the Edwards Aquifer Contributing and Recharge Zones can therefore have significant negative effects on surface water quantity and quality. Such regions, with high groundwater and surface water interaction are better managed with water approaches that connect groundwater production limits to springflow and stream flow.

While conjunctive groundwater management is generally recognized as an appropriate strategy for sustainable water use–because it helps prevents subsidence, preserves environmental flows, and can prevent saltwater intrusions caused by groundwater withdrawals–it is especially critical in areas with a high degree of surface and groundwater interaction. Conjunctive management is even more important when such areas are located in semi-arid regions like Central Texas. The Edwards Plateau in Central Texas exemplifies such hydrogeology as the plateau acts as a huge catchment area for the Trinity and Edwards Aquifers. The rains that fall over the northern and western parts of the Hill Country make their way, via streams and rivers, to the southwest part of the plateau which comprise the contributing and recharge zones for these aquifers. The complexly fractured karst geology of the plateau on its southeastern edge, where it abuts the BFZ illustrates this phenomenon most clearly in the many springs that emerge along its edge. Simply put, springflow is groundwater becoming surface water. Many of those springs provide baseflow—"the component of surface water flow that can be

[78] *Id*. 27-29.

attributed to groundwater discharge"—for Central Texas streams and rivers.[79] As TWDB's recent comprehensive aquifer study reports "Groundwater contributions to surface water are greatest in East Texas and around major springs in the Hill Country."[80] In fact the Edwards (BFZ) and the Edwards-Trinity (Plateau) are two of the three major aquifers that provide more than half of the baseflow to area streams as evidenced by the multitude of current and historical springs flowing from them.[81]

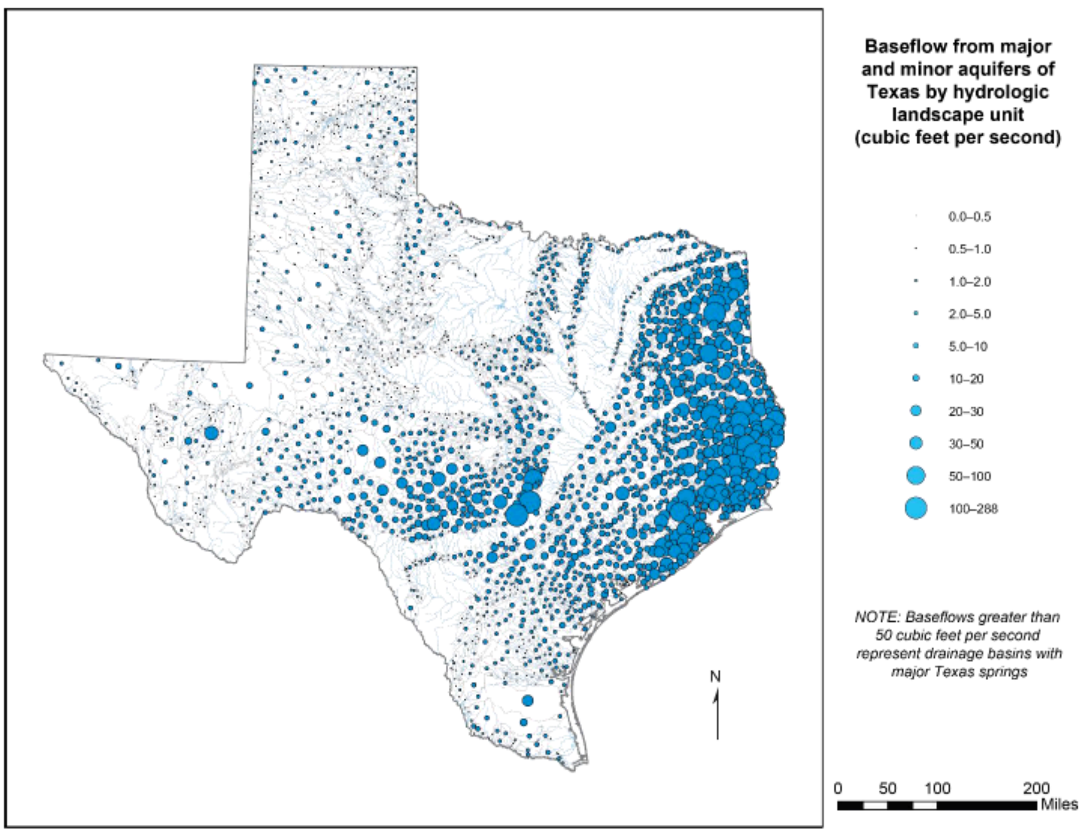

Figure 8: Baseflow from aquifers by hydrologic unit (in cubic feet per second), from *Texas Aquifers Study*, 2016.

[79] *Id*. iv.
[80] *Id*. v.
[81] *Id*. v-vi.

Figure 8 shows baseflow from aquifers to surface water bodies and the cluster of blue dots in the center of map shows significant groundwater and surface water interaction across the Edwards Plateau but particularly along its southeastern edge, in the Balcones Fault Zone, as discussed above. The portion of Hays County governed by HTGCD, the focus of this report, is located in that vicinity very near where the Trinity and Edwards aquifers meet the BFZ, an area that recharges the Trinity Aquifer and contributes to Edwards Aquifer recharge as well. Clearly, such a high degree of surface water entering aquifers and, vice versa, groundwater emerging as surface water baseflow, demands management strategies that address that hydrogeological reality. The lack of a thoroughly integrated conjunctive management regime poses serious threats to both groundwater and surface water quantity and quality.

While the fact that these two aquifers provide over half of the stream baseflow in the region is critical for this study, the connections between these aquifers is also key to making a case for more conservative, regionally coordinated, conjunctive water management in this area of Central Texas.

3.2 Declining Aquifers & Aquifer Interaction (Trinity & Edwards)

The most critical portions of the Recharge Zone for the Edwards Aquifer are governed by the Edwards Aquifer Authority, a groundwater management entity unique in Texas given its relatively strong regulatory authorities and ample resources; it is not subject to Chapter 36 of the Texas Water Code. A detailed examination of EAA is beyond the scope of the paper, and its formation and functions is documented in detail on its website[82] and evidenced in the results of the Edwards Aquifer Recovery and

[82] Edwards Aquifer Authority, "Legislation and Policy," Edwards Aquifer Authority.

Implementation Program.[83] Although recent study of inter-aquifer flows indicate significant flows from the Hill Country segment of the Trinity Aquifer into the Edwards Aquifer and the karst features surface water bodies that lie over the former constitute part of the contributing zone of the latter, EAA's stronger protections do not apply to the Trinity Aquifer. Given the interaction between the two aquifers, in the form of water flowing from the Trinity into the Edwards, the lack of robust protection could weaken EAA's ability to conserve the Edwards groundwater that keeps endangered species alive and provides drinking water to the City of San Antonio.

The Hill Country portion of the Trinity Aquifer is, by comparison, poorly protected and thus experiences greater declines in the absence of stricter regulations. For over a decade pumping from the Middle Trinity aquifer has exceeded recharge, meaning that the de facto policy is currently one of "managed depletion" or aquifer mining which runs counter to the official policy articulated in HTGCD's management plan.[84] Confirming this assertion, one recent DFC monitoring study found that the aquifer is losing 1.3 feet per year on average across GMA 9; even in the relatively wet years following the most recent drought, "the aquifer remains in deficit… relative to conditions in 2008."[85] That persistent trend "is about twice the average rate of decline for the DFC (-0.6ft/yr). The results of this study suggest that the aquifer is under stress and is presently being depleted at a rate that could compromise achieving the DFC in the future."[86]

The lack of robust protection and the unsustainable DFC for the Trinity Aquifer could significantly negatively impact the Edwards Aquifer despite its stronger regulatory

[83] RECON Environmental Inc. et al., Edwards Aquifer.
[84] David Baker, "GMZs," e-mail message to Norman.
[85] Hunt and Smith, Desired Future, 4.
[86] *Ibid*.

safeguards. Inter-aquifer flows between the Trinity and Edwards suggest that, in order to protect the Edwards over the long term, the Hill Country portion of the Trinity also needs

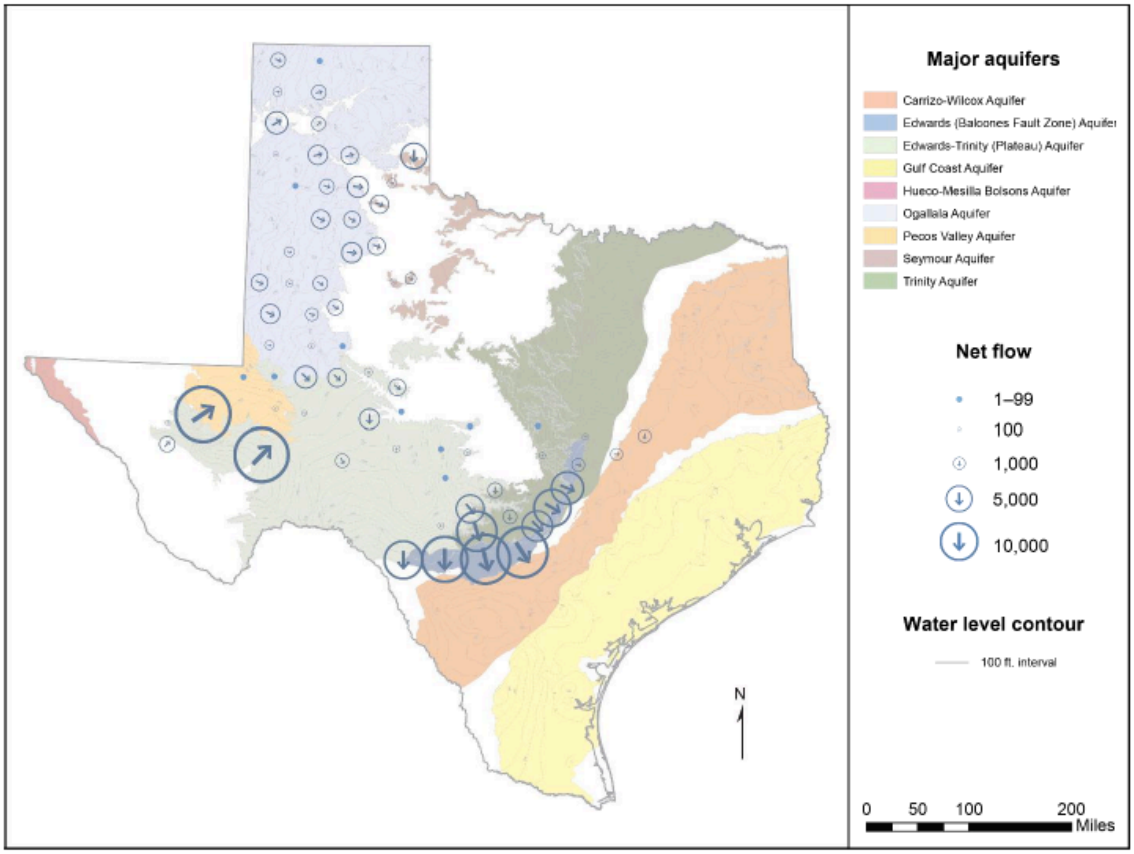

Figure 9: Relative magnitude of inter-aquifer flows where data or models are available, from *Texas Aquifers Study*, 2016.

stronger regulatory measures. TWDB's aquifer study has identified this region as one of two areas in the state with significant aquifer interaction: "Groundwater modeling indicates that flows between aquifers occur primarily in the Hill Country and in the Pecos Valley."[87] Figure 9 shows some of the larger and more concentrated inter-aquifer flows between the Trinity and Edwards in the Central Texas portions of those aquifers.

[87] Texas Water Development Board, *Texas Aquifers*, vii.

Although these maps provide a useful way of understanding the unique and vulnerable hydrogeology of the region, the inter-aquifer flows are based largely on computer models rather than measurement of actual aquifer levels in a variety of conditions over an appropriate timespan, such as shorter-term potentiometric studies and longer term monitoring based on frequent (daily) well level readings.[88] TWDB offers the following caveats as "key points" to preface this chapter of the study: Estimates are based on models that include no direct measurements of inter-aquifer flow; many models include "no flow" boundaries so cannot produce any estimates; and the models weren't designed for this purpose so results vary widely.[89] As I will discuss at more length in the following chapter, studies based on frequent well monitoring and potentiometric variation can yield a more accurate picture of available groundwater and can help scientists determine varying flow patterns in specific areas of an aquifer such as a springshed.

3.3 Drought, Flood, and Climate Change Impacts on Central Texas

Declining aquifers become a more serious threat to water quantity in the context of drought and climate change. Less quantity also translates into diminished water quality as pollutants become more concentrated in groundwater and surface water. Further, extreme flooding in a region with high surface and groundwater interaction can impact water quality as well. Central Texas is already known for its extremes in meteorological conditions; the region experiences lengthy periods of drought punctuated by heavy rainfall events that have earned it the moniker "Flashflood Alley." According to the National Oceanic and Atmospheric Administration (NOAA)'s "Billion-dollar Weather

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[88] Potentiometric studies use well level data to create potentiometric surface maps, which show groundwater level contours that indicate expected groundwater flow paths from higher to lower subsurface elevations.

[89] Texas Water Development Board, *Texas Aquifers*, 38.

and Climate Disasters" website, Texas leads the nation with 94 disasters between 1980 and 2017 that caused in excess—often far in excess—of one billion dollars each.[90] Droughts and floods are among the most economically costly disasters among seven categories in NOAA's database.[91] The effects of climate change include increasingly severe and longer drought periods, making it imperative to manage groundwater resources with the expectation that we will experience longer periods of drier conditions during which aquifers will not receive any recharge from rainfall.

Rising temperatures, more extreme droughts, and more severe flooding all exert increasing pressure on water resources—especially groundwater—with potential for significant decreases in water quantity and harm to water quality and the ecosystems they support. According to a 2014 study of climate change impacts in Central Texas, models projected "an increase in average maximum temperature of about 3º F" for Hays and Travis counties during the period 2025-2049 when compared with historical temperatures during the period 1984-2004.[92] Increasing temperatures matter because municipal and agricultural water use increases with hotter weather and because higher temperatures increase evaporation. As with many areas of the Great Plains region, floods and droughts are expected to become more frequent and more severe with longer droughts and heavier rainfall events.[93] Such intense flooding washes more pollutants into the surface water bodies and—in karst regions—into groundwater reservoirs as well. Stormwater runoff increases the loading of suspended solids, *E Coli*, and many other pollutants such as herbicides, pesticides, and fertilizers, which can damage wildlife habitat and make water

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[90] National Oceanic and Atmospheric Administration, "Billion-Dollar Weather," National Centers for Environmental Information.
[91] *Ibid*.
[92] Gordon, Summary of Climate.
[93] *Ibid*.

unsafe for consumption and recreation.[94] Low flow in streams, springs, and rivers can also harm habitat by diminishing the amount of dissolved oxygen (DO) that aquatic creatures need to survive. Drought conditions can also lead to higher nutrient loads, which encourage algae blooms and further reduce DO.[95]

The *Third National Climate Assessment* predicts that climate change induced groundwater shortages are likely across the southern U.S. where groundwater supplies are under pressure as is true of the Trinity Aquifer in Hays County and other areas of the Hill Country. Texas aquifers, like most of the Great Plains aquifers, will continue to be,

> … highly vulnerable because climate change is projected to reduce water availability, increase demand, and exacerbate shortages. Confidence is therefore judged to be high that groundwater aquifers will be influenced by climate change through impacts on recharge and by increased groundwater use…[96]

On the eastern edge of the Hill Country along the I-35 corridor, demand will certainly continue to rise if population growth and development patterns continue as they are currently occurring.

3.4 Population Pressure and Sprawl Development Pattern

As has been thoroughly documented, Central Texas has experienced unprecedented population growth over the past decade and that growth is projected to continue. The Austin Metropolitan Statistical Area (MSA), which includes Hays County, is projected to double to over 4.3 million by 2045.[97] While urban centers like San Antonio and Austin expand, their neighboring, comparatively rural, counties absorb more

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[94] Whitehead, P.G. et al. "A Review of the Potential Impacts of Climate Change on Surface Water Quality." *Hydrological Sciences Journal*, 54 (2009).
[95] Gordon, 2014, Np.
[96] U.S. Climate Change Research Program, *Climate Change*.
[97] Department of Planning, City of Austin, *Austin Area*.

and more of that growth as outlying suburban communities multiply to provide affordable housing options for homebuyers. Hays County, located just southwest of Austin, has ranked among the fastest growing counties in the nation for several years running and was the third fastest growing county in 2016.[98] Much of that growth has taken the form of conventional, car-oriented, suburban subdivision—or sprawl—development patterns. In fact an analysis of 2016 census and housing data from the U.S. Postal Service found that the Austin and San Antonio metropolitan areas have been losing population density even as population growth boomed between 2010 and 2016 with both experiencing a 5% or greater decrease in average neighborhood density.[99] That suburban development occurs primarily in unincorporated parts of these counties or in extraterritorial jurisdictions where municipalities lack the legal authority to control over how and where the growth happens. Studies have repeatedly shown that such development and the infrastructure it requires puts more strain on natural resources, especially water. Because Hays County residents and businesses rely primarily on groundwater, the Middle Trinity Aquifer—already identified as an aquifer "under stress"—faces even greater threats as growth continues in this form.[100] As early as 2000, before the recent waves of population growth, scientists at TWDB were predicting drawdowns of the Trinity Aquifer in the 50-100 foot range as early as 2010.[101] The more recent studies referenced above confirm that the aquifer is indeed in already in decline even as it faces greater demand.

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[98] Thorne, "Hays County."
[99] Kolko, "Seattle Climbs."
[100] Hunt and Smith, *Desired Future*, 4.
[101] Texas Water Development Board, *Groundwater Availability*, 1.

3.5 Environmental Flows, Groundwater Dependent Ecosystems, and Wildlife Habitat

Declining groundwater quantity not only causes potential drinking water shortages for humans but also less functional ecosystems due to lower surface water flows. The Meadows Center for Water and the Environment defines environmental flows as: "the freshwater needed to maintain water quality and the overall health of streams, creeks, and rivers, wetlands, and bays and estuaries. All of these systems depend on adequate environmental flows to deliver social and economic benefit to Texans."[102] In 2007, the legislature charged TCEQ to adopt environmental flow standards, based on stakeholder recommendations, "adequate to support a sound ecological environment, to the maximum extent reasonable considering public interests and other relevant factors."[103] This addition to the water planning and surface water permitting processes acknowledges the ecosystem services that fresh water provides such as aquifer recharge, water quality protection, and wildlife habitat. Instream flows, flows in rivers or streams, are of interest for this study area, although the concept encompasses freshwater inflows into bays and estuaries. Rooted in surface water planning and regulation, the environmental flows regime established a decade ago also recognizes the connections between groundwater and surface water. As with many other pieces of the water planning and regulatory code, environmental considerations are one among many that the stakeholder committees, voting members, water regulators, and agency staff must take into consideration. They will be important for this report in attempting to evaluate how effective GMZ rules and regulations may be at conserving groundwater to maintain sufficient instream flows for wildlife habitat and water quality in the face of increasing human consumption and drought severity compounded by climate change.

[102] Meadows Center for Water and the Environment, *Environmental Flows*.
[103] Tex. Water Code 11.1471(a)(1).

Environmental flows also link water quantity to water quality, an essential connection for understanding how groundwater and surface water interact as part of larger ecosystems especially in areas like the Hill Country with such the high degree of communication described above. Instream flows are further divided into 3 categories:

1. Subsistence flow is the "minimum streamflow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for the survival and recolonization of aquatic organisms."[104]
2. Pulse flows are the "high flows within the stream channel that occur during or immediately following a storm event."[105]
3. Base flows are "the range of average flow conditions, in the absence of significant rainfall events, that may vary depending on current weather patterns"[106]

Of most interest here are subsistence flows which represent the threshold at which ecosystem services begin to fail and base flows capable of preserving higher water quality and wildlife habitat in addition to a host of other important ecosystem services such as the economic factors discussed in the following section. Pulse flows are important as well as they provide prime conditions for breeding for some freshwater aquatic species. It is beyond the scope of this report to provide a comprehensive account of the ecosystem services that instream flows provide in the Cypress Creek watershed, but it is worthwhile to consider some key services that ample flows provide in the form of water quality and wildlife habitat. They will help to determine how a GMZ for Jacob's

[104] 30 Tex. Admin. Code § 298.1(10).
[105] 30 Tex. Admin. Code § 298.1(8).
[106] 30 Tex. Admin. Code § 298.1(2).

Well can be structured in a way that preserves spring flow for healthy watershed ecosystems and high water quality.

Like much of the region, the Cypress Creek watershed is home to Groundwater Dependent Ecosystems (GDEs), which are "ecosystems which rely on the surface expression of subsurface presence of groundwater."[107] GDEs occur in large numbers across the Edwards Plateau and GMA 9 has among the "highest GDE index values, indicating… the highest potential to contain GDEs" especially karst areas overlaying the Edwards, Edwards-Trinity, and Trinity aquifers.[108] In these areas, wildlife depends on reliable baseflow from aquifers into springs and creeks. Probably the most famous example is the Barton Springs Salamander, one of several related species of endangered spring dwelling salamanders, which the U.S. Fish and Wildlife Service listed as endangered in 1997. These salamanders and a number of other spring and karst creatures have brought federal regulatory pressure to bear on protecting groundwater resources to ensure the ecosystems services that adequate base flows provide. Since 2005, several other salamanders have been identified and protected, and the same could happen for Jacob's Well as well as other springs in Hays County.

A team of Biologists from Zara Environmental and Texas State University published the results of a recent study of *Eurycea pterophila* (the Fern Bank Salamander) to determine whether the site, Jacob's Well, is home to a single recognized species or more than one distinct species adapted to both spring and cave environments and whether this particular population is isolated from other closely related salamanders inhabiting Central Texas springs. Further study is needed to determine whether or not this

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[107] Gou, Gonzales, and Miller, "Mapping Potential," 99.
[108] *Id*. 104.

population is indeed currently isolated and rare enough to merit listing as endangered.[109] More conclusively, the greater number of samples following high spring flow and the presence of juvenile salamanders so deep within the cave strongly suggests that reproduction occurs deeper within in the cave meaning that the "aquifer habitat may serve as breeding grounds or vital refuge during drought."[110] Jacob's Well is one of the only springs in Central Texas large and therefore accessible enough to study spring-dwelling creatures such as the Fern Bank salamander in its natural habitat. In addition to strengthening scientific understanding of these elusive creatures, this important study reinforces the need to enact management strategies for minimum springflow protections.

Just as water quality is critical to maintaining biodiversity, so too is biodiversity critical to water quality. A healthy aquatic ecosystem keeps water cleaner than one out of balance, so protecting environmental flows necessary to maintain habitat also protects water quality. When Jacob's Well stopped flowing in 2000, the segment of Cypress Creek was placed on the EPA's 303d list of impaired waters; costly cleanup measures would have been enforced had it remained there. Should the Fernbank Salamander be listed as endangered, aquifer depletion and reduced springflow could spur costly litigation. Thus, maintaining environmental flows for healthy ecosystems would be a proactive measure to avoid expensive water quality and endangered species habitat mitigation.

3.6 Economic Vulnerability

In the area covered by the HTGCD, economic, cultural, and environmental assets are deeply interdependent. The potential economic impacts of over-pumping groundwater

[109] Krejca et al., "Genetic Characterization," 11.
[110] *Id*. 8.

pose serious threats to the local economy that thrives precisely because of the scenic qualities and recreational opportunities that draw both tourists and new residents to the area. The culture is also shaped by the kinds of work and play supported by the area's natural resources, especially the unique characteristics of the land, water, and wildlife. Under the current GMA 9 DFC, the likely adverse environmental impacts could irreversibly damage the land, water, and wildlife fundamentally changing the culture and harming the local economy upon which the local government entities, schools, and communities rely. Economic losses would stem from significant declines of land values and tourism resulting in significant losses of property and sales tax revenues as well as local jobs and income.

As discussed above, rapid population growth and property value increases in Austin have driven residential development in Hays County and resulted in higher land and home values in outlying bedroom communities. According to a 2013 Meadows Center for Water and the Environment study, long-term low flow conditions would reduce property values in areas near the creek by 25 to 45 percent and degraded water quality by would reduce them by 20 to 30 percent.[111] Studies in Central Texas and Colorado have consistently found that "the closer properties are to natural resources like creeks, the higher the average price and potential property tax income."[112] A 2013 report estimated that along "the perennial Cypress Creek, tax appraisal values for properties adjacent to the stream channel total over $33 million."[113] Although the City of Wimberley does not currently collect property taxes, the report estimates that Woodcreek

[111] Meadows Center for Water and the Environment, *Understanding Hill Country Water Resources Assessment of The Economic Contribution of Cypress Creek to The Economy of Wimberley, Phase II Final Report*, 8.
[112] *Id.*, 37.
[113] *Id.*, 36.

and Wimberley could bring in over one million dollars annually for just the properties along Cypress Creek.[114] Given the rapidly soaring property values across the Austin MSA over the past decade, that number would be significantly greater now in 2018.

The same rugged beauty, natural resources, cultural and recreational opportunities that make the Wimberley Valley an attractive place to live also draw tourists from around the state and across the globe. The Meadows study reports that "in 2010, revenues from the tourism and hospitality sectors totaled more than $65 million, generated $391,799 in sales tax revenues (accounting for 70% of the total sales tax revenues collected by the City of Wimberley) and employed at least 517 local residents. Approximately $13.75 million in wages can be attributed to tourism and hospitality."[115] Further, lodging in Wimberley generated $1,271,832 in the first quarter of 2013 and $6,277,345 in 2012.[116] A continued aquifer deficit in the Middle Trinity could mean that Jacob's Well stops flowing once again causing the wet portion of Cypress Creek downstream from the spring to dry up and halt its discharge into Blanco River which, aside from supplying significant recharge Edwards Aquifer, represents another significant source of tourist revenue for the valley. Needless to say, a dried up creek bed will have substantially less appeal for potential residents and tourists than a flowing one. A significant drop in tourist dollars would cost Wimberley and Woodcreek lost jobs and sales tax revenues. Jacob's Well, Cypress Creek, Blue Hole Regional Park, and the Blanco River comprise the economic engine of the Wimberley Valley and thus make it extremely vulnerable to economic decline should the groundwater cease to provide sufficient flows to draw residents and visitors alike.

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114 *Id.*, 8.
115 *Id.*, 9.
116 *Id.*, 14.

These economic threats, considered alongside vulnerable ecosystems, rapid population growth, climate change, and steadily declining aquifer levels, all within an especially sensitive and complex hydrogeological area, demonstrate the many reasons why recognizing surface water and groundwater interaction is so important to groundwater conservation for Hays County and the region that shares many of these characteristics and threats.

Chapter 4: Groundwater Management Zones in the Barton Springs Edwards Aquifer District and Hill Country Underground Water Conservation District

4.1 Barton Springs Edwards Aquifer Conservation District Case Study: Developing Groundwater Management Zones, Science, and Policies

Because of the close proximity, shared geology, and hydrological interconnections of BSEACD and HTGCD, BSEACD's GMZ approach serves as a felicitous case study by which to evaluate the how well GMZs will work in HTGCD and especially the Jacob's Well-Cypress Creek area. BSEACD also faced and continues to face many of the same threats now occurring in HTGCD. For these and other reasons discussed below, the BSEACD's experience in establishing GMZs based on preceding scientific study may provide a useful template for developing a similar system in HTGCD. For GCDs in other areas of the state, GMZs may help balance local control and regional coordination for more effective conjunctive water management. In areas where surface water and groundwater interactions are less pronounced and conjunctive water management may not be as imperative, GMZs may still provide GCDs with an effective tool for conserving groundwater more effectively by identifying more and less threatened areas of an aquifer.

4.1.1 Sustainable Yields and Drought Trigger Studies and Methodology

BSCEAD was created in 1987 and has had the advantage of strong enabling legislation, carefully defined aquifer-based boundaries, a highly visible and much loved spring, and an environmentally friendly political climate. Its boundaries were established—based on the best available scientific data—to cover the Barton Springs segment of the Edwards Aquifer and have since been expanded as aquifer dynamics within the Edwards segment and between the Edwards and Trinity are better understood after three decades of scientific study. Protecting the iconic Barton Springs has always been rallying point for the majority of Austin area voters as evidenced by the City's passage of the Save Our Springs (SOS) ordinances in the early 1990s to provide stiffer regulations for development in the Barton Springs Zone all of which lies within the District's boundaries. The relatively large spring has also been the subject of study for decades previous, so, for example, they were able to use data reaching back to the drought of record (DOR) in the 1950s to set some of their most important regulatory policies. Drawing on a wealth of data to more carefully calibrate models, BSEACD undertook studies to develop a Drought Trigger Methodology (DTM) and sustainable yield evaluation. These policies along with constant well monitoring and potentiometric studies laid the foundation for later designation of 6 major GMZs.

As early as 1990 BSEACD published a drought contingency plan based on well monitoring and statistical analysis in order to set reductions in pumping during 3 stages of drought. Over the following decade further data and multiple refined models all "indicated the potential for flow from Barton Springs to diminish significantly, or to cease flowing altogether under severe drought conditions and high rates of pumping."[117] The 2001 GAM model developed by TWDB had been calibrated to conditions of much wetter years and thus could not accurately account for extreme drought conditions, conditions now expected to return more frequently and intensely due to climate change. District scientists recalibrated the model using data from the DOR during the 1950s in order to conduct a sustainable yield study completed in 2004. The study "concluded that District had already reached the sustainable yield limits for the Edwards Aquifer."[118]

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[117] Barton Springs Edwards Aquifer Conservation District, *30 Years*, 6.

[118] Barton Springs Edwards Aquifer Conservation District, *Barton Springs/Edwards*, 17.

They found that if permitted pumping continued at 2004 levels—about 10cfs—during DOR conditions, Barton Springs would cease flowing. The sustainable yield modeling based on the revised GAM spurred the district to move to Conditional Production Permits for groundwater production from the Edwards, which meant that all further permits for Edwards pumping would be interruptible or subject to curtailments during drought conditions. In 2007, the district established Extreme Drought Withdrawal Limitation (EDWL) to set the total annual groundwater production cap at 8.5 cfs, with curtailments in place, to support the sustainable yield and drought management policies. The study and EDWL prepared the district for the first round of regional joint planning process during which they would "effectively set a maximum historic pumpage of 0.5 cubic feet per second" in order to maintain a minimum springflow of 6.5 cfs.[119] The resulting DFC adopted by GMA 10 states, "During extreme droughts, including a recurrence of the 1950s drought of record, monthly average springflow at Barton Springs shall not be less than 6.5 cfs."[120]

As these studies and the water planning process unfolded, the district sought to further improve aquifer management by establishing 6 major GMZs for the two aquifers within its jurisdiction and the significantly different areas within them: the Western Freshwater Edwards, the Eastern Freshwater Edwards, the Saline Edwards, the Upper Trinity, the Middle Trinity, and the Lower Trinity management zones. The permitting cap resulting from Conditional Permitting and the EDWL prompted BSEACD to create zones recognizing other portions of the aquifers that had "additional availability that could continue to be permitted on a firm-yield basis, even during extreme drought."[121] The

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[119] *Ibid*.
[120] Barton Springs Edwards Aquifer Conservation District, *DFCs for District*.
[121] Barton Springs Edwards Aquifer Conservation District, *Barton Springs/Edwards*, 14.

zones facilitate more effective management of the aquifers and subaquifer areas by specifying which kinds of permits can be issued in each zone and the conditions attached to those types of permits and uses.

4.1.2 Defining Boundaries and Intent Matrix for Zones

Historic hydrogeologic studies, well monitoring data, dye trace and potentiometric studies provided the district with an increasingly clearer understanding of the complex karst aquifer systems and informed the boundary setting process. Potentiometric studies of large numbers of wells over a short period of time are conducted to produce contour maps that "help characterize the quantity of water and direction of flow in an aquifer" under high and low flow conditions.[122] In conjunction with general geological knowledge of the BFZ and dye trace studies, it is possible to determine recharge areas and degrees of communication between aquifers and subaquifer areas and how that changes—especially in a karst system—under wetter and drier conditions. Potentiometric maps help scientists and regulators understand preferential flow paths of groundwater and pinpoint where the flow is directed by various geological features. For example the Balcones Fault lines, which pushed less permeable strata up against more porous karst layers redirect the flow of Edwards Aquifer groundwater from the northwest-southeast to southwest-northeast so that groundwater flowing from western Hays County towards the southwest is either forced northward towards Austin emerging at Barton Springs, southward toward San Marcos Springs, or possibly both depending on shifts in the dynamic groundwater divide (See Figures 10 and 11).

122 Barton Springs Edwards Aquifer Conservation District, *Water Level*.

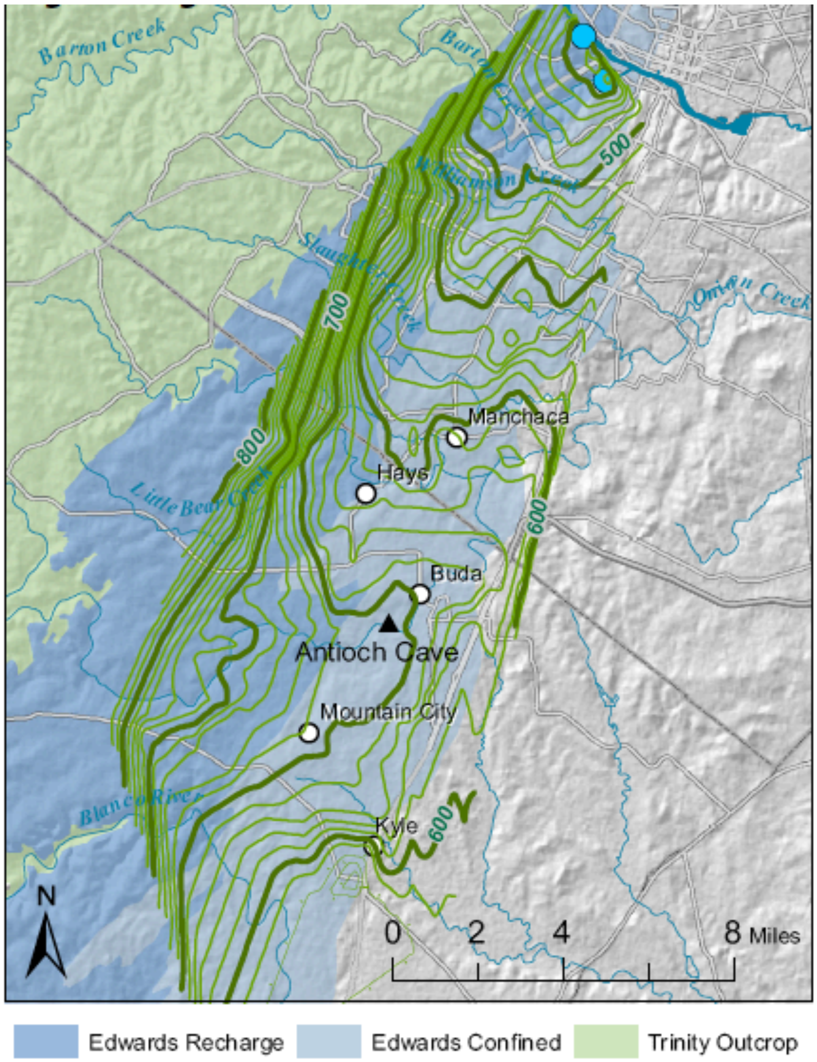

Figure 10: Potentiometric map showing water level contours in the Barton Springs Edwards Aquifer during high flow conditions, February 2002, from BSEACD Fact Sheet 0314.

Flow patterns are inferred from the declining water elevations from west to east and south to north. Figure 11 represents a more complete conceptual diagram, minus the elevation contours, of the groundwater flow being radically redirected in the “Confined Zone” by the faults in the BFZ.

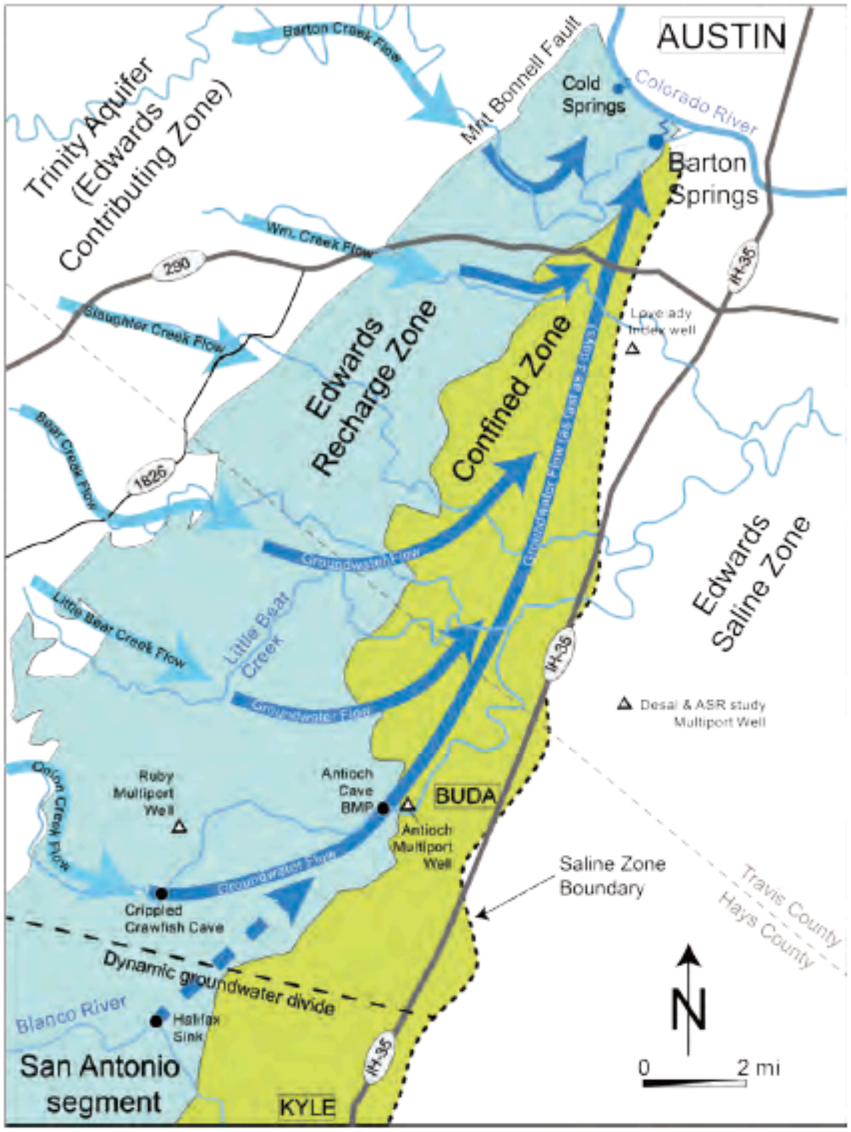

Figure 11: Conceptual flow diagram of the Barton Springs segment of the Edwards Aquifer, from BSEACD Fact Sheet 0817.

Years of study and monitoring have made it clear the dynamic and fluctuating character of the Edwards and the Middle Trinity Aquifers within the study area where groundwater levels are very responsive to weather patterns.[123] In contrast the Saline

123 *Ibid*.

Edwards GMZ, which borders the confined portion of the Freshwater Edwards zone to the east, is much less permeable so that both its recharge and discharge is minimal by comparison.[124] Those hydrogeological differences, therefore, call for very different management strategies.

The geological complexity of these different zones and the degree of their interconnectedness can be clarified to some degree by setting the boundaries of the zones both on the surface of the land as well as stratigraphically to understand how the different subsurface strata and confining features influence differing conditions in different areas. Figure 6 shows both the surface boundaries and simplified subsurface boundaries of BSEACD's management zones. Once the horizontal and vertical boundaries were determined with the help of scientists in a technical advisory committee. BSEACD developed an intent matrix to articulate prioritized management outcomes, regulatory limitations, pumpage permitting, well construction requirements, drought management strategies, DFCs, and MAGs for each zone. The matrix was used as part of the stakeholder process to promulgate rules in accordance with the policies laid out in the management plan. These GMZs with very different aquifer dynamics and intended outcomes can be managed accordingly. For example, BSEACD charges $0.38/1000gallons for water pumped from Freshwater Edwards while it only charges $0.17/1000gallons for water pumped from the Trinity.[125] The prices reflect the relative

[124] Barton Springs Edwards Aquifer Conservation District, *Barton Springs/Edwards*, 35.
[125] *Ibid*.

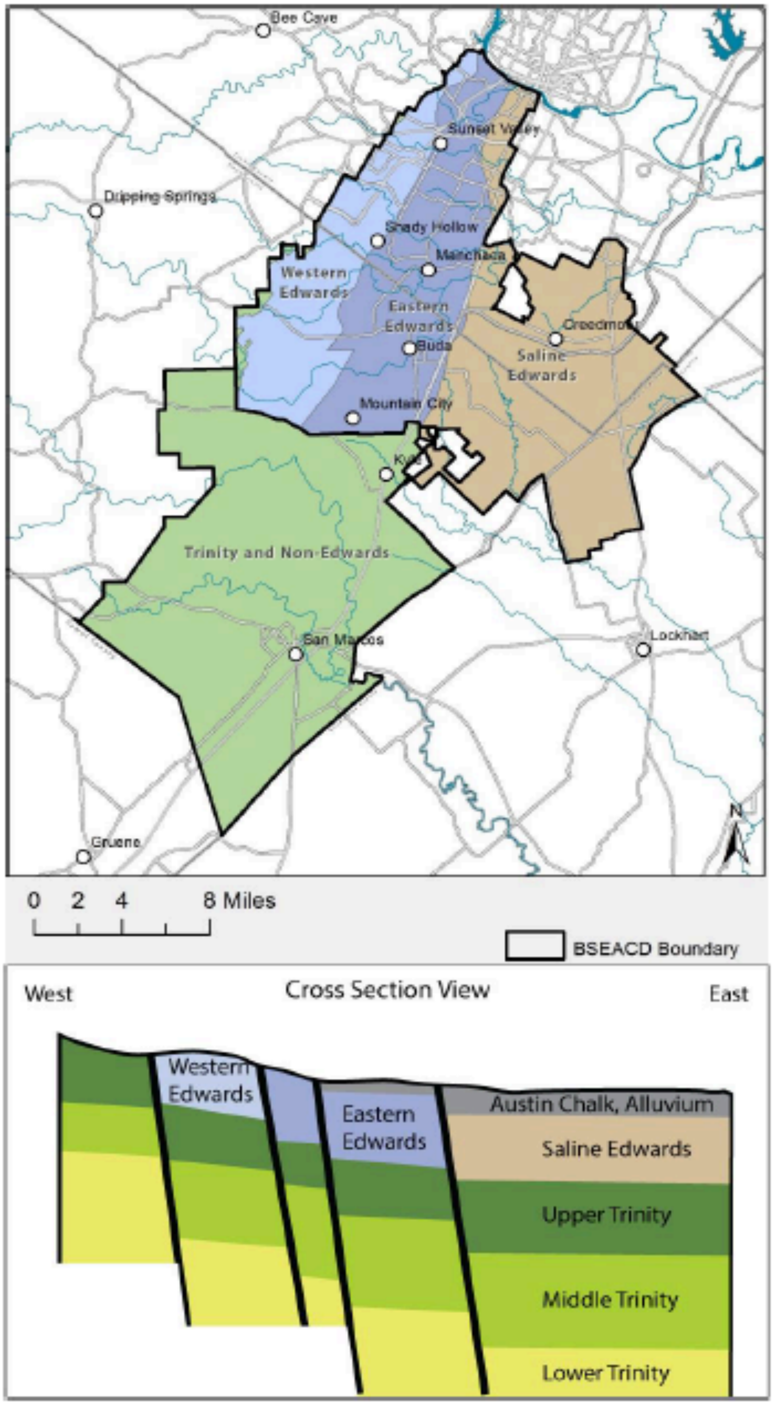

Figure 12: Map of existing management zones and cross section view of vertical management zone boundaries underground, from "Barton Springs Edwards Aquifer Conservation District Management Plan."

availability of groundwater in relation to the DFCs for each aquifer as understood when the GMZs were created.

Even more significant are intent differences reflected in the drought curtailment schedule: For the Freshwater Edwards permits issued after 2007 reach up to 100% even before “critical” drought conditions are declared, while the Saline Edwards permits require 0% curtailment even in “exceptional” drought and maximum curtailment for the Middle Trinity is only 30% (See Figure 13). The Trinity curtailment may be strengthened as the District has been granted more jurisdiction over the aquifer, with the eastern Hays County annexation in 2015, and has recognized greater pressure on groundwater from the Middle Trinity as well as more significant interaction between the two aquifers per recent studies cited earlier. Each of these drought stages is defined by a trigger or threshold at which the district declares the particular drought stage. Because the mandatory drought curtailment schedule is such a central feature and the crucial regulatory teeth of the GMZ system, it is important to understand how those triggers are determined, applied, and communicated to the general public in an accessible way. Constant monitoring and easy to grasp indicators of drought are key elements of the DTM developed and refined by BSEACD.

Drought Curtailment Chart										
Aquifer	Edwards Aquifer						Trinity Aquifer			
Management Zone	Eastern/Western Freshwater					Saline	Lower	Middle	Upper	Outcrop
Permit Type	Historical	Conditional				Hist.	Hist.	Hist.	Hist.	Hist.
		Class A	Class B	Class C	Class D					
Drought Stages										
No Drought	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Water Conservation (Voluntary)	10%	10%	10%	10%	10%	0%	10%	10%	10%	10%
Alarm	20%	20%	50%	100%	100%	0%	20%	20%	20%	20%
Critical	30%	30%	75%	100%	100%	0%	30%	30%	30%	30%
Exceptional	40%	50%[1]	100%	100%	100%	0%	30%	30%	30%	30%
Emergency Response Period	50%[3]	>50%[2]	100%	100%	100%	0%	30%	30%	30%	30%
Percentages indicate the curtailed volumes required during specific stages of drought.										

1 Only applicable to NDUs and existing unpermitted nonexempts after A to B reclassification triggered by Exceptional Stage declaration

2 Curtailment > 50% subject to Board discretion

3 ERP (50%) curtailments become effective October 11, 2015. ERP curtailments to be measured as rolling 90-day average after first three months of declared ERP.

Figure 13: Drought Curtailment Chart for Barton Springs Edwards Aquifer Conservation District Groundwater Management Zones.

4.1.3 Monitoring and Drought Trigger Methodology

The District first developed an adopted a DTM in 1990 but revisited the methodology in 2005 and adopted a revised DTM in 2006. Analysis of the earlier methodology found that redundant and sometimes faulty monitoring of many wells "indicated entry into drought too frequently, leading to lack of credibility and ultimately poorer response by the public" in addition to the use of multiple wells and triggers being "confusing and difficult to communicate to the public."[126] District scientists continued to track and evaluate the DTM and issued an updated methodology in 2013 with the intent

[126] Barton Springs Edwards Aquifer Conservation District, *Drought Trigger*, 4.

of better facilitating timely drought declarations and implementation as well as more accurately capturing aquifer-wide conditions with simpler indicators easily understood to the general public. The new DTM used only two indicators—Barton Springs flow and Lovelady monitor well levels—to set drought triggers based on the two main types of groundwater flow present in the aquifer, conduit flows and diffuse flows. The conduit flow system connected to Barton Springs responds rapidly to even minor recharge events, while the Lovelady well lacks that connection so its levels change much less significantly in response to recharge events. Monitoring both types of flow allows the District to identify drought conditions earlier and with more accuracy.[127]

Although the triggers are based on Edwards Aquifer indicators and do not include monitoring data from the Trinity, the triggers apply to the Trinity, because conditions in Barton Springs reservoir are thought to be reasonably indicative of regional drought conditions.[128] The report concludes that, while the DTM works well for protecting the Middle Trinity Aquifer, further study and evaluation will be necessary to confirm that conclusion.[129] The much-simplified DTM also achieved its purpose of improving communication of drought management to the public with two simple indicators. An accessible graphic display of the regularly updated indicators is featured prominently on the District's website effectively conveying conditions of a complex aquifer in a simple manner (See Figure 14).

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[127] *Id.*, 1.
[128] Dupnik, interview by the author.
[129] Barton Springs Edwards Aquifer Conservation District, *Drought Trigger*, 26.

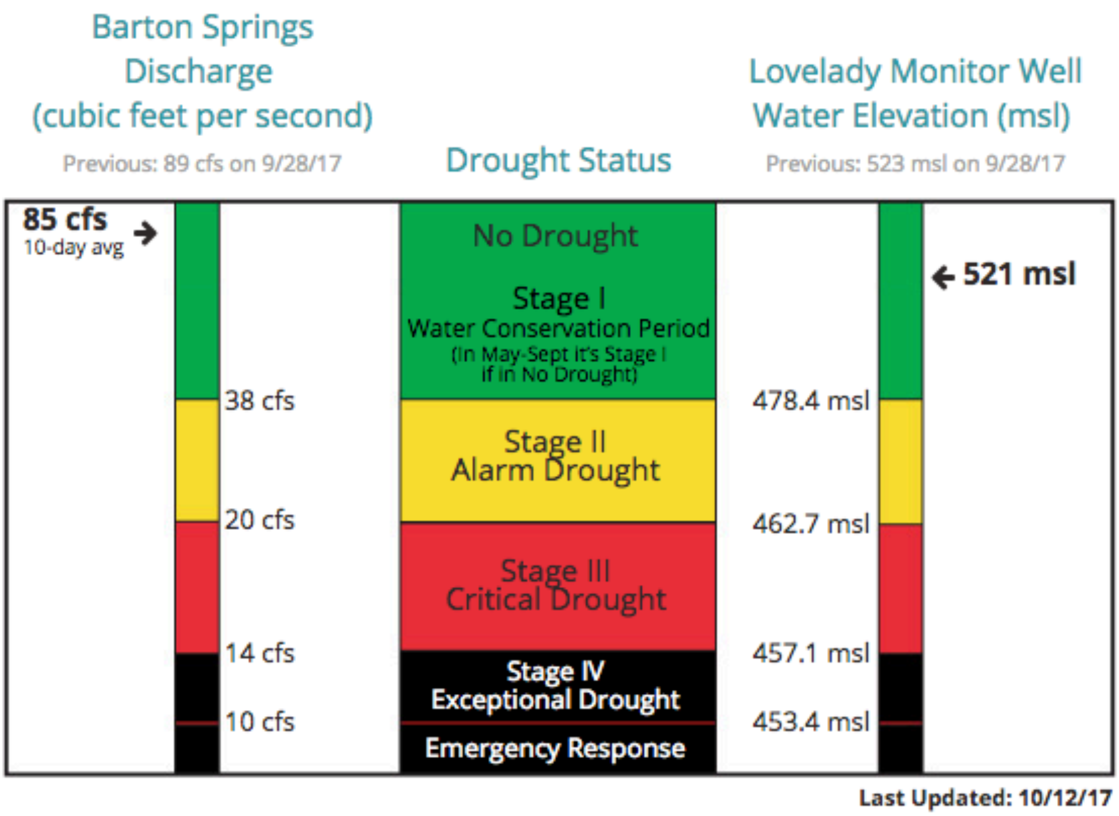

Figure 14: Barton Springs and Lovelady Well Drought Status Indicators from BSEACD website landing page.

4.2 Evaluating Groundwater Management Zones in BSEACD

Are GMZs effective tools for sustainable groundwater management in Hays County and the Hill Country Region of Central Texas? That is, can they help successfully mitigate the threats discussed above in order to balance water conservation for environmental flows, economic benefit and producing plentiful, clean water for human consumption? For BSEACD, GMZs have provided an effective way to refine a comprehensive and integrated groundwater management system. As Figure 15 shows, the amount of permitted water increases more slowly after the move the conditional permitting and even more so after the GMZs were created. The widening gap between permitted pumping and actual pumping suggest the system has proven effective at encouraging groundwater conservation whether voluntarily as a result of education or mandatorily as a result of curtailments, although wetter years following the 2011 drought may account for significant reduction in pumping as well.

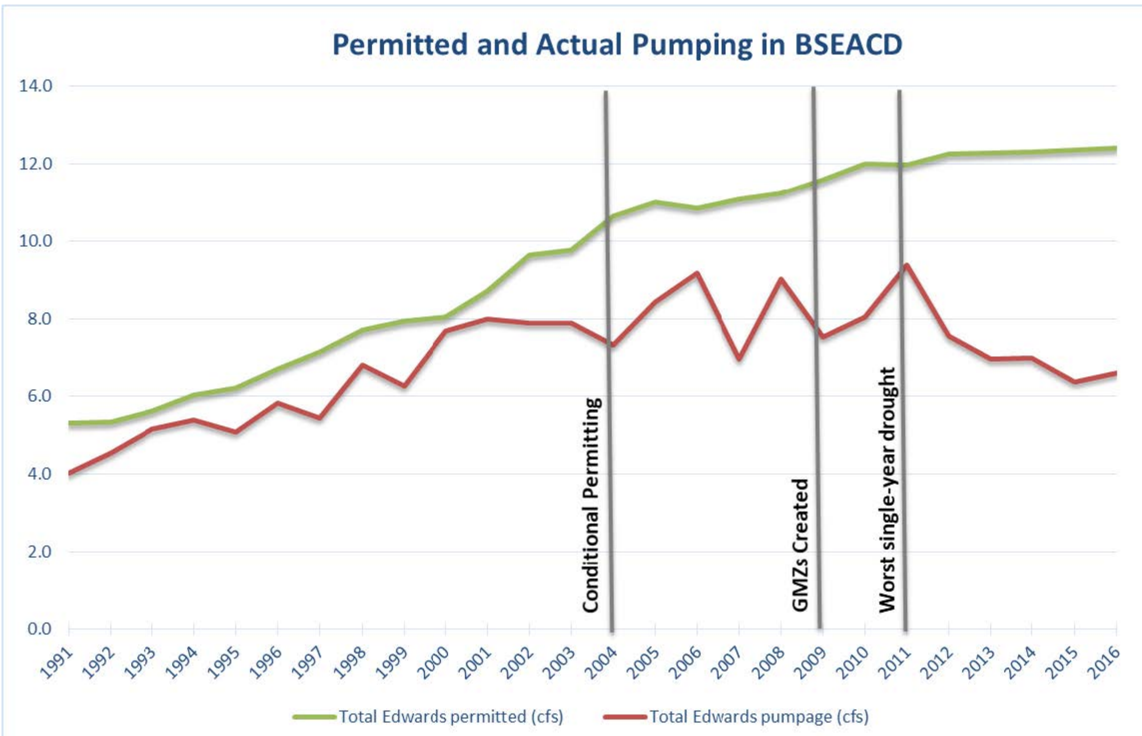

Figure 15: Chart showing permitted and actual pumping and key events. Permit and pumping data provided by BSEACD Senior Geologist Brian Hunt.

The District's science-based approach allows for more responsive adaptive management in the context of rapid changes in climate and demand. While BSEACD's management zone strategy—integrated with other important policies and rules—has proven effective according to some indicators, improvements in funding for additional monitoring and study as well as regional coordination could strengthen the regulatory system even further.

4.2.1 An Effective Tool for Long-term Aquifer Protection?

Despite the skepticism of GMZs in his case for regional, aquifer-level groundwater management mentioned above, John Dupnik, General Manager of BSEACD, believes that they represent "one of the most powerful" tools for managing groundwater.[130] Because they allow GCDs to differentiate permits based on aquifer conditions or use in each zone, GMZs are more effective at responding to changing conditions with adaptive management strategies. They also provide a more solidly defensible way to set DFCs and determine MAGs to protect subaquifer areas vulnerable to depletion from aquifer-wide DFCs that would not conserve groundwater in a sustainable fashion. Because the process of setting boundaries, determining sustainable yield and permit conditions including drought-induced pumping curtailments, is more science-based, the resulting regulatory system tends to be less controversial and subjective in Dupnik's view.[131] In that sense, they do provide some degree of political insulation from and leverage in the joint regional planning process. Scientific study and monitoring are key to making GMZs work, for example distinguishing shallower from deeper parts of an aquifer and tracking monitor well levels in pumping "hot spots" to identify potential dewatering zones. Having the system in place paired with ongoing monitoring and study improves key indicators that make possible the type of adaptive management essential to effective long-term water conservation strategies.

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[130] Dupnik, interview by the author.
[131] *Ibid*.

Although science-based, the public rulemaking process is the result of many hydrogeological studies, expert vetting, as well as stakeholder and public involvement. "the product of numerous scientific studies conducted by the District's hydrogeologists, vetted through technical consultants and advisors, reviewed and commented on by stakeholders and the public, and approved by the Board."[132] Even given that sometimes lengthy process, Dupnik said that a major advantage to the GMZ system and developing localized DFCs and MAGs was "less cumbersome" than GMA planning and DFC setting by consensus among the GCDs in the GMA. The GMA must still approve a district's GMZ DFCs, but the process of setting the DFC is carried out at the district level with local constituent and stakeholder input. The process of setting drought triggers involves a mix of science and finding "reasonable sweet spots" for curtailment.[133] For example, reasonable for Edwards is total curtailment, because district stakeholders deemed Barton Springs going dry an unreasonable DFC. Trinity values were also deemed "reasonable" but not based on actual volumes of groundwater, in part, because comparatively less was understood about the aquifer at the time. A greater number of Trinity wells and constituents in BSEACD's recently annexed jurisdiction present opportunities—discussed in the following chapter—for moving toward a more science-based approach similar to the Freshwater Edwards GMZs in conjunction with the district's DTM and DFC.

In addition to the greater stability that data-driven decision making and public support lend to the GMZ regulatory system, it also provides cover from expensive litigation most GCDs can ill afford. The recent cases *Edwards Aquifer Authority v. Day* and *Edwards Aquifer Authority v. Bragg* reaffirmed Texas Courts' deference to the Rule

[132] Barton Springs Edwards Aquifer Conservation District, *Barton Springs/Edwards*, 21.
[133] Dupnik, interview by the author.

of Capture defining groundwater as private property. The former opened up the possibility for a regulatory taking claim by establishing a property interest in groundwater, and the latter decided that the Authority's denial to expand the Braggs' permit constituted a regulatory taking. But Dupnik reported that the District did not think the GMZ curtailment system put them at risk, because of the high bar for takings claims. Rather than outright denials of permits or of requested volumes, these are conditions of permit that may require total cessation of pumping. Therefore, no permanent taking has occurred. The party still has the permit, just not the right to pump when drought triggers are in effect.[134] That said, nothing in §36.116(d) prohibits GCD from including denial of permits or types of permits as part of a GMZ's rules. For example, BSEACD does not permit any new wells exempt or nonexempt in the Upper Trinity (or Trinity Outcrop) Management Zone.[135]

4.2.2 Environmental Flows and Water Conservation Progress

BSEACD GMZs have been an important part of maintaining water quantity and quality in the Barton Springs segment of the Edwards Aquifer as evidenced by preserved flow of Barton Springs even during the droughts of 2009 and 2011. Balancing the water budget at increasingly sustainable levels plays a large role in preserving Barton Springs baseflow, which protects existing wells and the environmental flows necessary to maintain valuable endangered species habitat. According to Brian Hunt, Senior Hydrogeologist at BSEACD, springflow data during extreme drought is the most important indicator by which to evaluate the effectiveness of the District's GMZ

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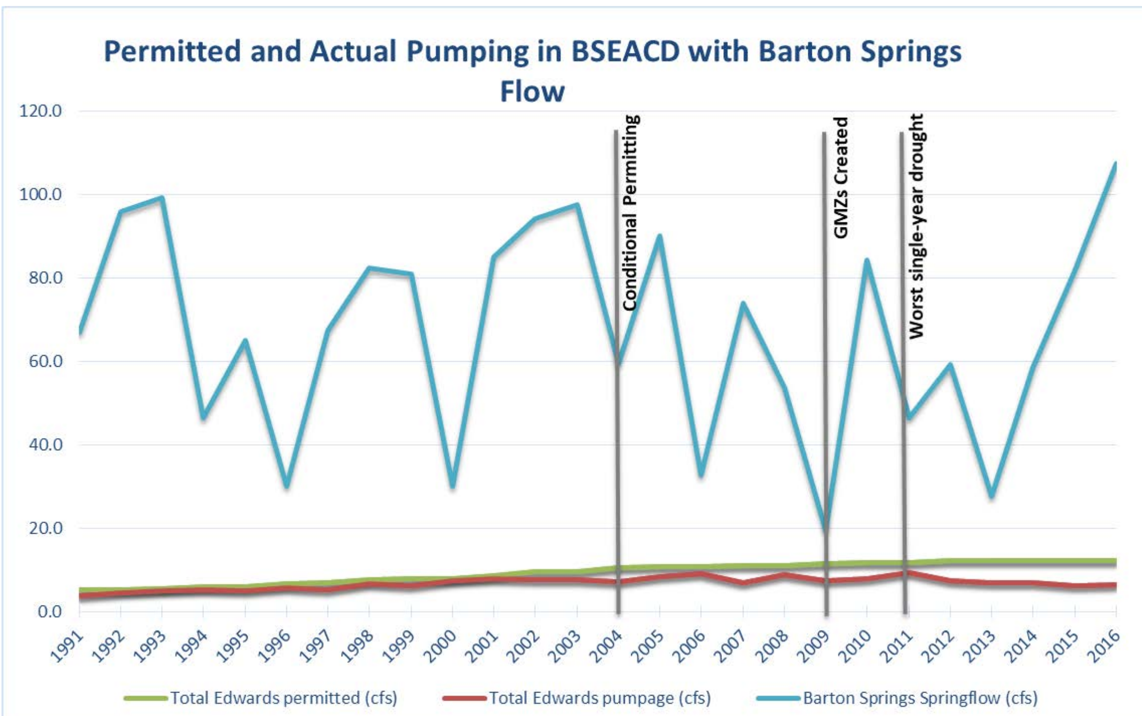
[134] Dupnik, interview by the author.

[135] Barton Springs Edwards Aquifer Conservation District, "Management Zones."

regulatory system.[136] Marcus Gary, Senior Hydrogeologist at EAA noted that the Authority uses the same metrics to show the effectiveness of their much more robust regulatory system, "cumulative effects of curtailment on aquifer levels which translates into springflow."[137] Hence constant monitoring of water quantity in the form of aquifer levels and springflow is paramount to demonstrating effective conservation and preserving environmental flows. Figure 16, below, suggests the GMZ system was effective at maintaining higher springflow of 46.5 cfs in 2011–a more extreme drought year than 2009 when springflow dropped to 19.6 cfs significantly higher than the minimum springflow expressed in the DFC.



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[136] Hunt, interview by the author.
[137] Gary, interview by the author.

Figure 16: Chart showing permitted and actual pumping with Barton Springs springflow and key events. Permit and pumping data provided by BSEACD Senior Geologist Brian Hunt. Barton Springs data from USGS *National Water Information System: Web Interface*.

Water quantity protects water quality by ensuring sufficient Dissolved Oxygen (DO) for habitat protection for the Barton Springs Salamander. Studies on DO and salamander survival were a key component of the DFC decision-making process; they indicated that springflow needed to be higher during extreme drought than could be guaranteed with drought plan and EDWL in place at the time.[138] Even though scientists have not yet confirmed the existence of an endangered species in the Cypress Creek Watershed, maintaining environmental flows at a level to support healthy habitat is part of the comprehensive strategy set forth in the Watershed Protection Plan for keeping water quality levels high. Therefore it is a useful indicator, linking water quantity to water quality, for evaluating the effectiveness of regulatory measures designed to conserve groundwater for creek flow and springflow such as GMZs. Springflow at Barton Springs has consistently been high enough to keep DO levels sufficient for habitat protection for the variety of aquatic wildlife including the endangered Barton Springs Salamander (*Eurycea sosorum*).

4.2.3 Improvements: Local Control and Regional Coordination

In terms of improvements that could be made to the GMZ system, Dupnik emphasized the need for more scientific studies and more state resources to gather and analyze aquifer-related data. Science-based arguments are a must, he reiterated, because they are more defensible and help sway the legislature to support further improvements to

[138] *Id.*, 16.

water management and conservation statutes especially in terms of funding. GMAs receive no financial support from the state, so that the joint planning processes are essentially unfunded mandates for GCDs already stretched thin in terms of time and resources. Dupnik insisted that GMA joint planning should receive funding as do Water Planning Groups.[139] With adequate funding, the scientific data to support more sustainable planning could be developed at the regional level. As District Hydrogeologists Brian Smith and Brian Hunt have observed in making the case for more data-driven evaluation through monitoring and scientific studies rather than simulations, regional DFCs "could be considered consensus yield" as opposed to a sustainable yield.[140] Incorporating localized data into regional planning would likely render more sustainable DFCs

Dupnik is confident that GMZs will be effective long-term and could be improved over time. As the District engages in more study and monitoring of the Trinity Aquifer in Hays County, they hope to refine the rules and conditions governing those zones. He expects that several new Trinity monitor wells in Hays County will yield better data on what triggers and curtailment should be as part of a wider DFC monitoring network. By way of example he asked, "Are Edwards triggers really the best?" Replying tentatively, "There may be a better Trinity indicator" to more accurately signal drought triggers and foster more sustainable aquifer management.[141] Of course communicating the results of studies and monitoring to the public is crucial to the success of water conservation efforts. For Dupnik, the BSEACD's real challenge is to balance simplicity of metrics while adding more complexity to the monitoring system, saying that it's important to

[139] Dupnik, interview by the author.
[140] Hunt, "Assessing the Impacts."
[141] Dupnik, interview by the author.

understand and be able to monitor the complex aquifer system but to also be able to communicate the need for conservation—in the form of pumping curtailment and other permitting conditions—with a very simple indicator for constituents, legislators, and the news media. In short "communication is a very important piece of the puzzle" in improving the effectiveness of the GMZ approach in any geographic context.[142]

When queried specifically about whether GMZs could be as potentially effective for protecting Jacob's Well and Cypress Creek given HTGCD's limited authority and resources compared to BSEACD, Dupnik did not hesitate to reply affirmatively noting that it could be an important tool elsewhere in the District as well.

4.3 Alternative Case Study: Hill Country Underground Water Conservation District's Use-Based Approach

To illustrate the flexibility of §36.116(d) of The Texas Water Code, this section will examine a somewhat different management zone approach taken by the Hill Country Underground Water Conservation District (HCUWCD) at a smaller more focused scale. The management zone subsection, like much of the Texas Water Code, is written in such a way that it allows for wide latitude in interpretation and implementation making it adaptable to a variety of geological and geographical contexts. HCUWCD covers Gillespie County, in the heart of the Hill Country, one county to the West of Hays County with Blanco County in between. While this more rural area is not facing the extreme population and development pressures, it is growing significantly especially in the area surrounding Fredericksburg perhaps one of the more famous tourist destinations in Central Texas. Long known for its peach orchards, the area has also been at the forefront of developing the Texas viticulture industry. Agricultural uses and tourist related

[142] Dupnik, interview by the author.

municipal water consumption in and around Fredericksburg exert pressure on groundwater especially during times of drought during the summer season. To review, §36.116 allows different rules for different zones if the district finds that "conditions in or use of an aquifer differ substantially from one geographic area of the district to another." While BSEACD's GMZ approach is based on geological and hydrological "conditions in" the different aquifers and subdivisions of them in their jurisdiction, HCUWCD's approach is based on "use of," as well as hydrogeological conditions in, different aquifers and aquifer subdivisions.

4.3.1 HCUWCD's High Historical Groundwater Use Areas

As early adopters, HCUWCD created rules for a two-tiered system of regulatory protection under §36.116 in the 1990s soon after the Texas Legislature amended Chapter 36 to include this rule-making and regulatory authority.[143] The District's Rule 9 grants the board the power to designate a first tier zone, termed a High Historical Groundwater Use Area (HHUA), based on water levels, production levels, increases in the number of permitted wells, and cones of depression. Hence use is much more prominent a factor in identifying and establishing the boundaries of these zones. The rule allows them to impose more stringent production limits, increase well spacing, or deny the permit.[144]

Although HCUWCD put Rule 9 in place in the 1990s, the Board only established two HHUAs in the summer of 2006. HHUAI and HHUAII are both just outside of the City of Fredericksburg and are relatively small (See Figures 17 and 18). Both HHUAs require more restrictive conditions for new permits to produce groundwater for

[143] Hill Country Underground Water Conservation District, *District Rules*, 29.
[144] *Ibid*.

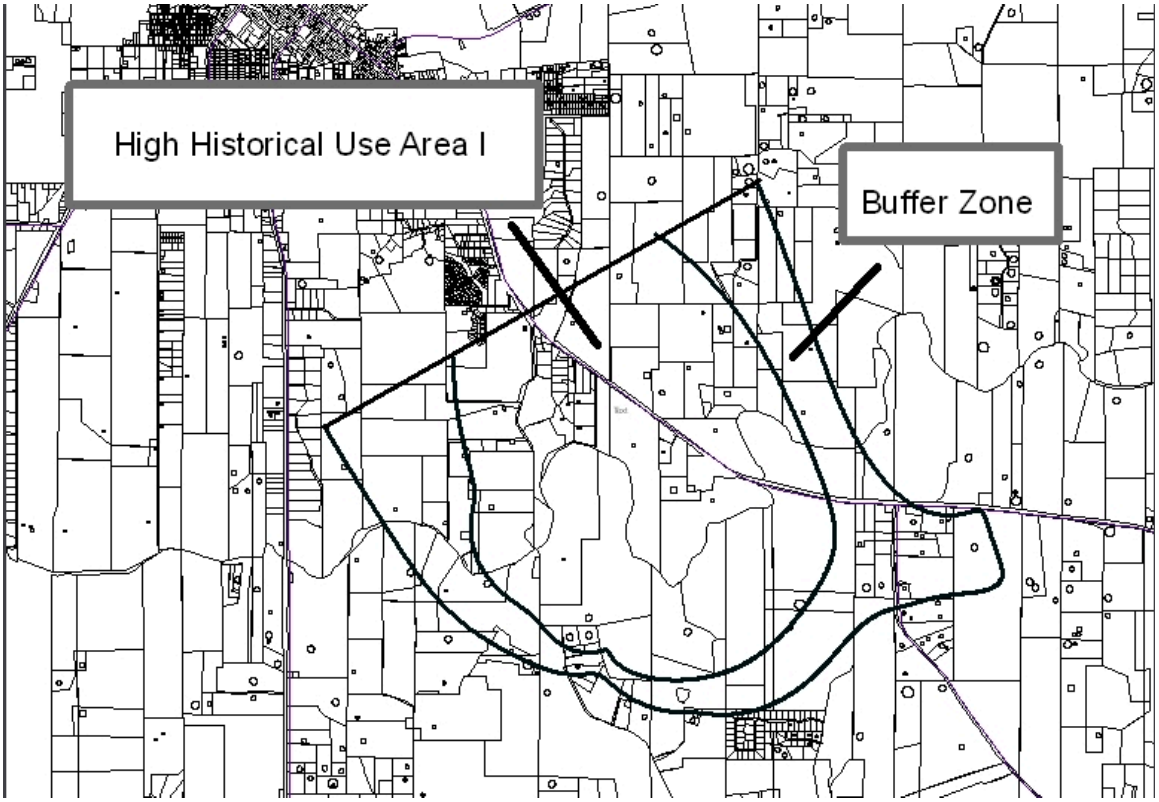

Figure 17: Map of HHUAI with Buffer Zone from HCUWCD's website.

municipal, irrigation, and commercial uses but not for domestic or livestock wells. They also double well spacing inside the HHUA and Buffer Zone. The City of Fredericksburg had pumped in both areas for municipal water supply in the past, so these spots were more vulnerable to drought conditions. Rather than framing these regulatory mechanisms as designed to protect the aquifers themselves or springflow, the District explains that the HHUAs are "meant to protect existing historic pumpage and to alleviate the possibility of taking the next more restrictive designation of a Critical Groundwater Depletion Area."[145] According to Paul Tybor, Manager of HCUWCD, the two HHUAs have been so successful in preventing aquifer mining—defined as pumpage exceeding recharge—they

[145] Hill Country Underground Water Conservation District, HHUA I and HHUA II.

have never had to declare a Critical Groundwater Depletion Area even during extreme drought years like 2011.[146]

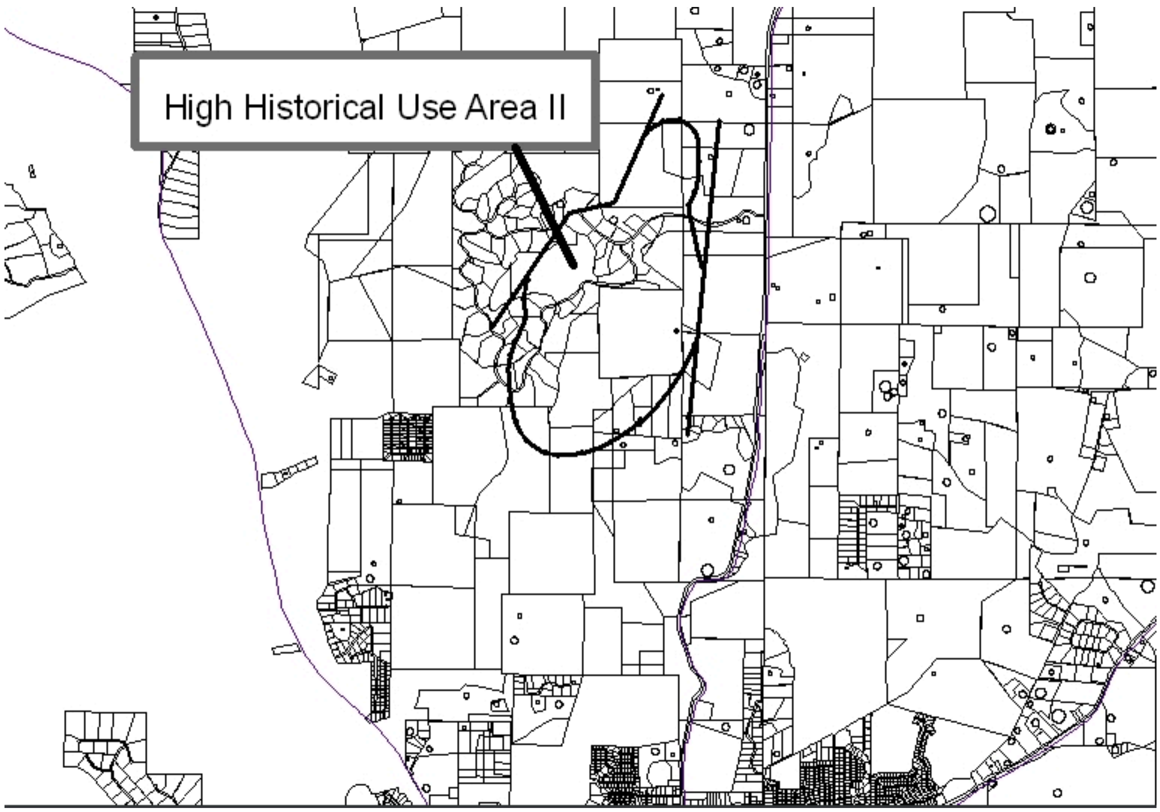

Figure 18: Map of HHUAII from HCUWCD's website.

4.3.2 HCUWCD's Critical Groundwater Depletion Areas

The District's Rule 9 also grants the Board the power to designate a second tier zone, termed Critical Groundwater Depletion Areas.[147] As with HHUA designations, the

[146] Tybor, interview by the author.

[147] "If evidence of drawdown of the water table or reduction of artesian pressure in an area of an aquifer indicates an aquifer mining situation, that is, a non-sustainable yield, or to ensure the compliance of meeting the Desired Future Conditions (DFC) of an aquifer as provided for in the District's Management Plan, or in consideration of such local climate indicators such as the Local Drought Index, Palmer Hydrological Drought Severity Index published by the National Oceanic and Atmospheric Administration

District solicits comments from and provides aquifer data to well owners in the proposed area. After posting notice of the designation and a period to submit written comments, the Board holds a public hearing allowing oral comments before the Board votes on the CGDA.

CGDAs are divided into Category One and Category Two classifications. The first category is applied to an area with climate-induced depletion and is cancelled when climatic conditions allow for adequate recharge.[148] The second category is applied to an area with production-induced depletion, although climate still may be a factor just not the primary one.[149] Category Two CGDAs until the aquifer shows "long-term reversal of the nonsustaining condition" to the extent that ensures meeting the DFC.[150] Both CGDA classifications allow HCUWCD to deny permits in the CGDA, set production limits to stop aquifer mining, require meters on permitted wells or increased well spacing, and recommend production limits for exempted wells. Permitted Well owners must submit reports on groundwater production quantity based on meters or estimates so that the District can monitor compliance. As a part of their Drought Management Plan, the Board can declare a CGDA designation at any time conditions warrant it. Such a designation during a drought triggers pumping curtailments for all permitted wells in Gillespie County not just within the CGDA up to 50% reduction in maximum demand during extreme drought. The curtailments do not include exempt domestic or livestock wells. Lastly, all permits issued contain a clause explaining that they could be included in a CGDA and subject to the restrictions described above.

(NOAA), or other drought indicators the Board may declare the area a Critical Groundwater Depletion Area (CGDA)."
Hill Country Underground Water Conservation District, District Rules, 31.

148 Tybor, interview by the author.

149 *Ibid*.

150 *Ibid*.

4.4 EVALUATING HIGH HISTORICAL GROUNDWATER USE AREAS AND CRITICAL GROUNDWATER DEPLETION AREAS IN HCUGCD

Because of their focus on pinpointing smaller areas, protecting historical users, and responding to climactic events and aquifer recovery, HCUGCD provides a useful alternative approach some aspects of which may be more appropriate for HTGCD. Like HTGCD, HCUGCD has few resources and even fewer staff. Borrowing elements from this approach that could make the rule change more politically palatable and financially feasible for HTGCD. One significant difference in context is the set of much more conservative DFCs adopted for HCUGCD's four different aquifers by GMA 7.

HCUGCD Manager Paul Tybor believes that these are effective regulatory tools for long-term groundwater management. He sees HHUAs as "a great way to look at specific areas that are not meeting the DFC and make more stringent rules, for the areas that need protection, that don't apply across the board" for the entire county.[151] "I don't know any other way to do that," he added.[152] He explained that, the aim is to protect high historical users based on production while also protecting the aquifer. The fact that the District has never had to designate CGDA corroborates the effectiveness of the HHUA approach. When asked about conserving groundwater to protect surface water baseflows, Tybor pointed to the fact that some of the aquifers in their jurisdiction provide flow to the Pedernales River. Like the Blanco River, the Pedernales has alternating losing and gaining segments the latter fed by springflow from these aquifers. In fact, Pedernales flow is one of the key indicators for determining drought conditions and levels in

[151] *Ibid*
[152] *Ibid*.

HCUGCD.[153] Even though conjunctive management is not at the center of HCUGCD approach, the management zones do provide protection for springflows that support surface water base flows by maintaining adequate aquifer levels.

Compared with the BSEACD's pathway to establishing GMZs, HCUGCD's rule change and subsequent designations did not require as much time and resources. TWDB's sustainable yield modeling determined there was about 12-14 acre-feet of groundwater available for production without causing aquifer mining before the DFC process was in place. Tybor said that the earlier modeling turned out to be fairly reliable and that, "so far, the DFCs are producing in line with the MAGs."[154] In other words the DFCs based on later modeling confirmed earlier model estimates. For Gillespie County models were sufficient, because of the difference in hydrogeology up on the Edwards Plateau further away from the BFZ. Although the Middle Trinity and Edwards Aquifers produce some groundwater in the District, they are relatively small yields compared to the Ellenburger Aquifer with historically heavy municipal and agricultural pumping.[155] In terms of the process of forming and regulating the HHUAs, Tybor also emphasized the importance of education and outreach. Because the §36.116(d) rules were adopted so long ago and because the HHUAs are relatively small, many permit applicants are simply unaware that they exist and their proposed well may be within one of them. He pointed out that everyone in the BSEACD is within a GMZ and thus more likely aware of the regulations than the smaller number of HCUWCD well owners in the HHUAs and Buffer Zones in. Reaching out to affected parties and inviting them to be a part of the process of determining boundaries and permitting conditions has been critical to their success.

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[153] Hill Country Underground Water Conservation District, "Local Drought."
[154] Tybor, interview by the author.
[155] Hill Country Underground Water Conservation District, "Gillespie County."

When asked about the vulnerability of this system to takings litigation, Tybor expressed concern that the District could be sued if they denied a permit in designated CGDA. Since they have not yet declared CGDA, they have never had to deny a permit outright. Given this possibility, Tybor suggested that more protections for GCDs against such suits could strengthen Chapter 36 especially with respect to management zone rules. He added that the legislature needs to deal with the rule of capture issues sooner than later to prevent these types of conflicts.[156]

The following chapter will consider precisely why and how a GMZ for Jacob's Well and Cypress Creek would be effective at protecting environmental flows as well as water quality and quantity in the Wimberley Valley and possibly beyond. Both approaches will be considered and evaluated as potential strategies for HTGCD as each has its own merits, which may or may not be applicable.

[156] Tybor, interview by the author.

Chapter 5: Groundwater Management Zones in the Hays Trinity Conservation District

This chapter will examine the advantages and potential pitfalls of establishing a GMZ in HTGCD encompassing the Jacob's Well Springshed and Cypress Creek Watershed. The chapter will first explore how such management will help mitigate the threats to water quantity and quality unique to the area and common to areas across the region and the state. Potential pitfalls or roadblocks to effective management will then set the stage for the final chapter's recommendations and conclusions about how make the most effective use of management zones.

5.1 Reasons Why a GMZ Will Work for Jacob's Well, Cypress Creek Watershed, and Other Areas in HTGCD

5.1.1 Shared Hydrogeological Characteristics and Inter-formational Flows

A GMZ for the Jacob's Well-Cypress Creek area would be effective first and foremost because it is BSEACD's immediate neighbor sharing not only common boundaries but also jurisdiction over the same aquifer, namely the Middle Trinity Aquifer. Accordingly it shares many of the same geological features and hydrogeological dynamics as the Barton Springs segment of the Edwards Aquifer. Marcus Gary of EAA confirms that areas of the Trinity Aquifer near the BFZ, like the Cypress Creek watershed, are more analogous to the Edwards than other areas of the Trinity to the west due because recharge occurs so rapidly.[157] Indeed, due to the high concentration of karst recharge features such sinkholes and caves, Jacob's Well exhibits a conduit flow quite similar—if much smaller in volume—to Barton Springs, and responds very rapidly to major rainfall events. Rather than storing rapid recharge in underground reservoirs, the

[157] Gary, interview by the author.

Well's behavior is shaped by the same fractured geology of the BFZ that sends Edwards Aquifer flow recharge north to Barton Springs and/or south to San Marcos Springs. In the Wimberley Valley, the Tom Creek Fault acts as a nearly impermeable subsurface barrier forcing water to discharge from Jacob's Well.[158] As Figure 19 shows, the rate of discharge at Jacob's Well correlates closely with rainfall events (measured here as groundwater elevation) and spikes upward directly after significant recharge events.

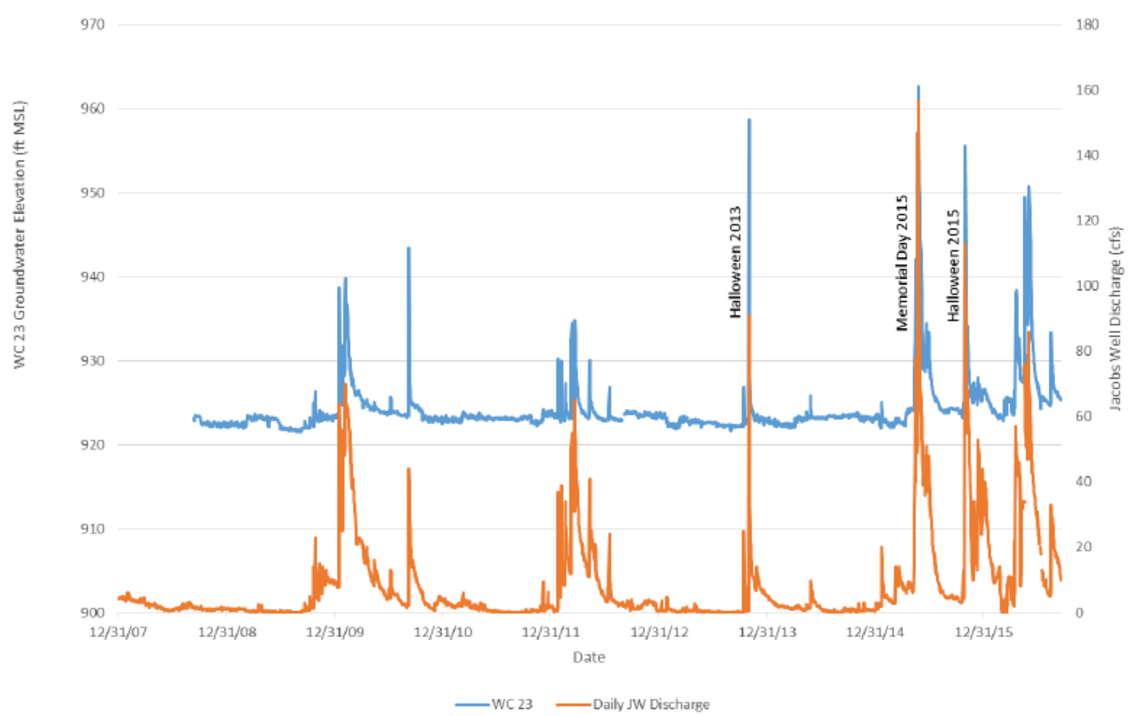

Figure 19: Groundwater Elevation and Jacob's Well Discharge.[159]

BSEACD has worked with the same dynamics in learning how to improve groundwater management and conservation, so can provide—and is, as I will discuss in further detail below, already providing—valuable guidance and assistance to HTGCD.

[158] Wierman and Hunt, "Groundwater Level," 8.
[159] Wierman, "Hydrogeology of Jacob's."

Because of their shared boundaries, aquifers, and geologies, a Jacob's Well-Cypress Creek GMZ could also make BSEACD's GMZs more effective.

As discussed in Chapter 4, the TWDB recognizes the BFZ as an area with the most dynamic high-volume groundwater and surface water interaction in the state and the Hill Country region stretching to the west from the BFZ as one of two regions in the state with a high degree of aquifer interaction. Recent studies confirm that inter-formational flows between the Middle Trinity and Barton Springs Edwards aquifers do indeed occur. Water discharging from the Middle Trinity through the mouth of Jacob's Well provides the water to the wet portion of Cypress Creek, which wends its way to the Blanco River in the Village of Wimberley. The Blanco, like many Hill Country rivers—such as the Pedernales and the Llano—is characterized by losing and gaining segments typical of karst geology. Porous karstic strata outcrops are exposed in the riverbed which make the river either "gain" groundwater via spring discharge or "lose" surface water into swallets that drain water underground. Whether or not the features gain or lose depends on elevation changes, aquifer levels, and groundwater flow patterns some of which can change with weather patterns and groundwater pumping. Such is the case with the Blanco River where Trinity outcrops are more common to the west of the Wimberley Valley and Edwards outcrops to the east. As Figure 20 demonstrates in a simplified form, "Water flows from the headwaters of the Blanco River to the outlets at San Marcos and Barton Springs or into the deep subsurface along various convoluted pathways," making it a significant source of recharge for both springs and both aquifers.[160]

[160] Smith et al., "Surface Water–Groundwater,"7640.

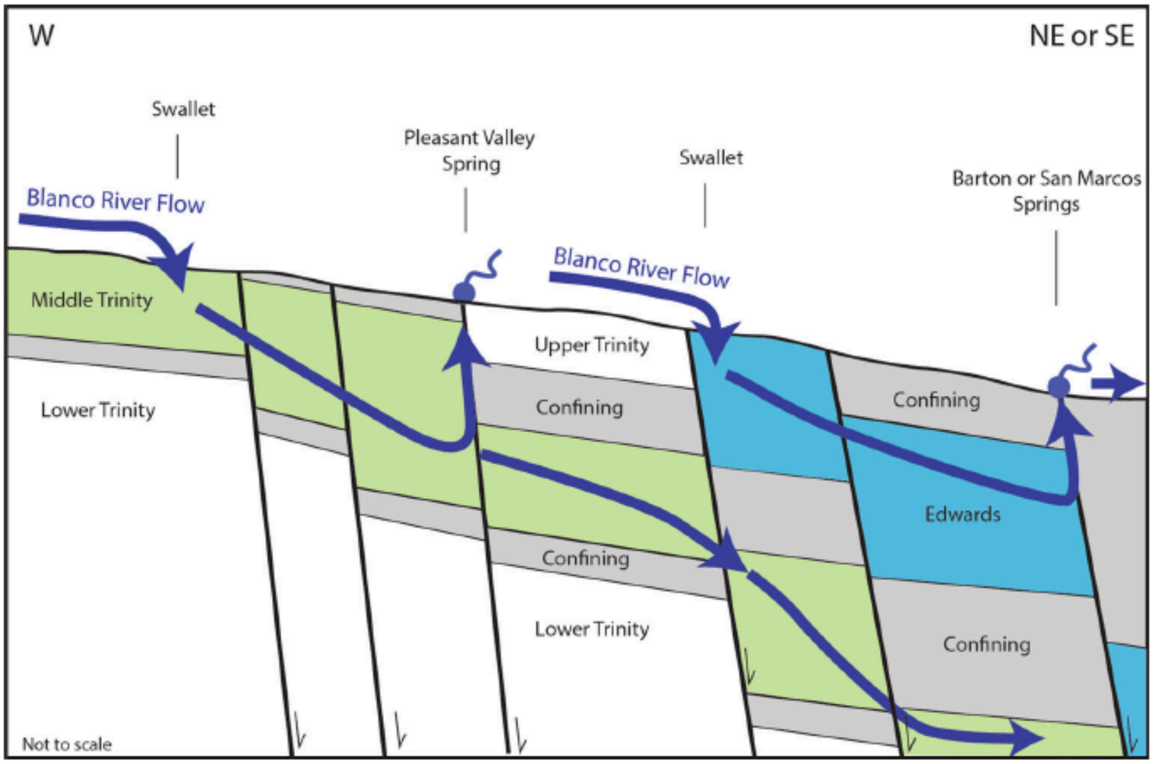

Figure 20: Schematic cross section along a portion of the Blanco River showing recharge to Middle Trinity and Edwards aquifers and iconic springs.

The connection between Jacob's Well/Cypress Creek and the Edwards Aquifer works much the same way Pleasant Valley Springs does in the schematic above. Water from the Middle Trinity Aquifer discharges from Jacob's Well and flows down Cypress Creek to the Blanco. Losing stretches in the Blanco, then, return the water underground into the Edwards Aquifer where it "can either flow south to discharge at San Marcos Springs, or it may flow north to discharge at Barton Springs, or it may flow in both directions."[161] Some of the water from Jacob's Well quite likely ends up in Barton Springs, so protecting Jacob's Well and hence the baseflows Cypress Creek and the Blanco River may help protect Barton Springs flow especially in times of drought.

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[161] *Ibid*.

Even if Jacob's Well alone is not responsible for significant Barton Springs recharge, it is abundantly clear the Middle Trinity Aquifer is. Coordinating management of these two highly communicative aquifers will be necessary to protect springflows and GMZs provide a way to recognize and respond to the dynamic relationships between these interconnected surface water and groundwater systems. Whether or not water flows south toward San Marcos Springs or north toward Barton Springs has to do with what scientists term the "dynamic groundwater divide," which shifts with aquifer levels changed by weather patterns and groundwater pumping. Onion Creek, an even more significant source of Edwards recharge than the Blanco, flows through HTGCD territory and is also comprised of alternating gaining and losing stretches. When Onion Creek experiences lower flows, subsiding groundwater pressure allows Edwards groundwater to shift its flow from south to north; in other words the groundwater divide moves southward essentially altering spring and aquifer recharge patterns. This underscores the need for GMZ-based regional coordination for more sustainable groundwater management discussed in more detail below.

5.1.2 Policies and Planning already in Place in Hays County and HTGCD

Some of the key policies and components of an integrated GMZ approach to groundwater management are already in place at HTGCD including recently increased monitoring, simple and sensible drought trigger indicators, and complementary efforts protect water resources in the area. As noted in the introduction developing science-based production limits and MAGs focusing on critical depletion areas is one of the guiding principles of the plan. But even more importantly, the GMZ concept is explicitly presented in the details of how the district will implement its policies and plans:

> In order to better manage groundwater resources the District may establish critical groundwater depletion areas, or management zones, for all sources of groundwater within the District. In each management zone the District may
>
> 1. Develop a DFC, specific to the area, that is responsive to the depletion issue
>
> 2. Calculate modeled available groundwater for the specific area
>
> 3. Determine and implement the proportional reduction of groundwater use for all classes of groundwater use that are established by the District.[162]

The important first step of establishing the concept as one of the sustainability policy implementation strategies has been taken, and some of the necessary monitoring and scientific study is already underway. HTGCD already has a network of monitoring wells distributed throughout und its jurisdiction to collect monthly aquifer level data, as well as several wells and springs that are continuously monitored in real time as a part of their drought contingency plan. Given the recent and ongoing studies and monitoring Hunt believes that "we have enough data" to begin the GMZ rule making process now especially if considered from a precautionary perspective.[163] With respect to developing a DFC and MAG specific to the area, Hunt recommended taking those steps after putting GMZ rules in place. Because the current GAM for the Hill Country portion of the Trinity Aquifer covers such a large area, it is "too crude to develop a DFC and MAG for a small area like the Jacob's Well springshed."[164] He also pointed out that the minimum springflow to maintain the health of the Cypress Creek watershed determined in the watershed protection planning process could serve as starting place or quasi-DFC to inform the rulemaking process.

Taking a cue from BSEACD, HTGCD has also established drought triggers based on fairly straightforward indicators prominently displayed on their website. Triggers and

[162] Hays Trinity Groundwater Conservation District, Groundwater Management, 28.
[163] Hunt, interview by the author.
[164] *Ibid*.

indicators have been set for the southern part of District, where drought status is determined by the Blanco River discharge rate, Jacob's Well discharge rate and the Mt. Baldy well water level."[165] Like BSEACD's indicators, HTGCD's are based on different type of groundwater flow represented by river discharge, springflow, and aquifer elevation determined by monitoring well levels. To date, there is no evidence that the district has developed a thoroughgoing analysis of their Drought Trigger Methodology (DTM). Yet, as Hunt points out, the District already has what amounts to a water budget for setting drought triggers: the minimal flow of Jacob's Well to ensure healthy habitat in Cypress Creek under drought conditions. He reiterated his earlier argument that HTGCD could set up the GMZ rules now and revisit the trigger methodology to target more severe cutbacks to reach the desired goals if necessary.[166]

In addition to being part of HTGCD's existing management and drought plans, the Jacob's Well-Cypress Creek GMZ is part of the Best Management Practices (BMPs) developed for the Cypress Creek Watershed Protection Plan currently in implementation with the express purpose of managing the watershed with more conservative policies than GMA 9's DFC.[167] Through an extensive stakeholder driven process developed strategies and goals to protect the Cypress Creek watershed including preserving flows to protect ground/source water quantity in order to maintain high water quality. Conducting scientific studies involving monitoring, analysis, and modeling, to recommend GMZ boundaries for watershed is one of the priority goals in support of this strategy.[168] Several important potentiometric studies have already been completed in Western Hays County

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[165] Hays Trinity Groundwater Conservation District, "Drought Management."
[166] Hunt, interview by the author.
[167] Meadows Center for Water and the Environment, *Proposed Best*, 42.
[168] Meadows Center for Water and the Environment, *Cypress Creek*, 85-86.

and Cypress Creek Watershed.[169] In fact, study has been underway for almost a decade to determine the catchment area or springshed for Jacob's Well; those studies will help inform the boundary-drawing and rule-making processes to create the GMZ.[170]

The Cypress Creek Watershed Protection Plan study of Ecosystem Services completed in 2011 attempted to define the catchment area for Jacob's Well.[171] In that report Vogl concluded, areas of eastern Blanco County in addition to local watershed were critical to protecting recharge of the spring.[172] The study analyzed a very large area, because it considered a broader set of ecosystems services beyond rapid-response recharge (See Figure 21). The second zone identified in the Blanco River basin also considered baseflow protection. Since 2011, hydrogeologists have determined that the portion of the Blanco included in Vogl's study primarily recharges Pleasant Valley Springs and the two springsheds may not be as interconnected as previously hypothesized.[173]

Wierman and Hunt's forthcoming study suggests that the recharge zone for the Well, the springshed, may actually be smaller and probably equivalent to the extent of the exposed Lower Glenn Rose formation, a highly karstic formation that is part of the Middle Trinity Aquifer (See Figure 22). When exposed on the surface, this formation delivers rapid recharge into the Jacob's Well conduits. The recent Raccoon Cave Dye Trace study attempted to determine the extent of the Dry Cypress Creek upper watershed contributes recharge to Jacob's Well with greater certainty. Its purpose was to evaluate

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[169] Barton Springs Edwards Aquifer Conservation District, *Potentiometric Surface*.
[170] Vogl, 2011. & Wiermann and Hunt, *Forthcoming*.
[171] Ecosystem Services are the benefits that natural resources provide as components of complex ecosystems as opposed to simply raw materials for human consumption. They are often assigned dollar amounts to illustrate their worth when conserved rather than extracted. They can include protecting other natural resources such as wildlife as well as supporting of industries and economies.
[172] Vogl, *Assessment and Value*, 10.
[173] Wierman and Hunt, "Groundwater Level," 3.

the hydrologic connection of karst features in the Lower Glenn Rose (Raccoon Cave) with Jacob's Well spring and area wells (See Figure 23). As Hunt explained, that study was designed to determine whether recharge is coming from the watershed beyond the smaller exposed Lower Glenn Rose portion of the watershed; however, the study was inconclusive as no dye was detected in Jacob's Well.[174]

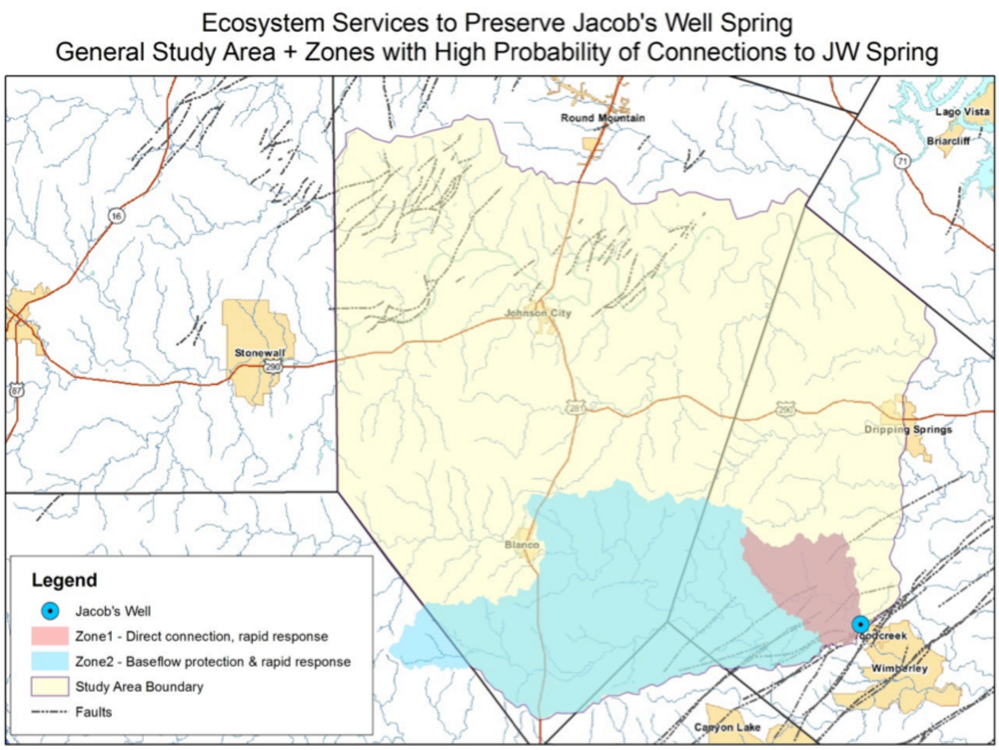

Figure 21: General study area and focus zones from Vogl, 2011.

[174] Hunt, "Pumpage, Springflow," e-mail message to author.

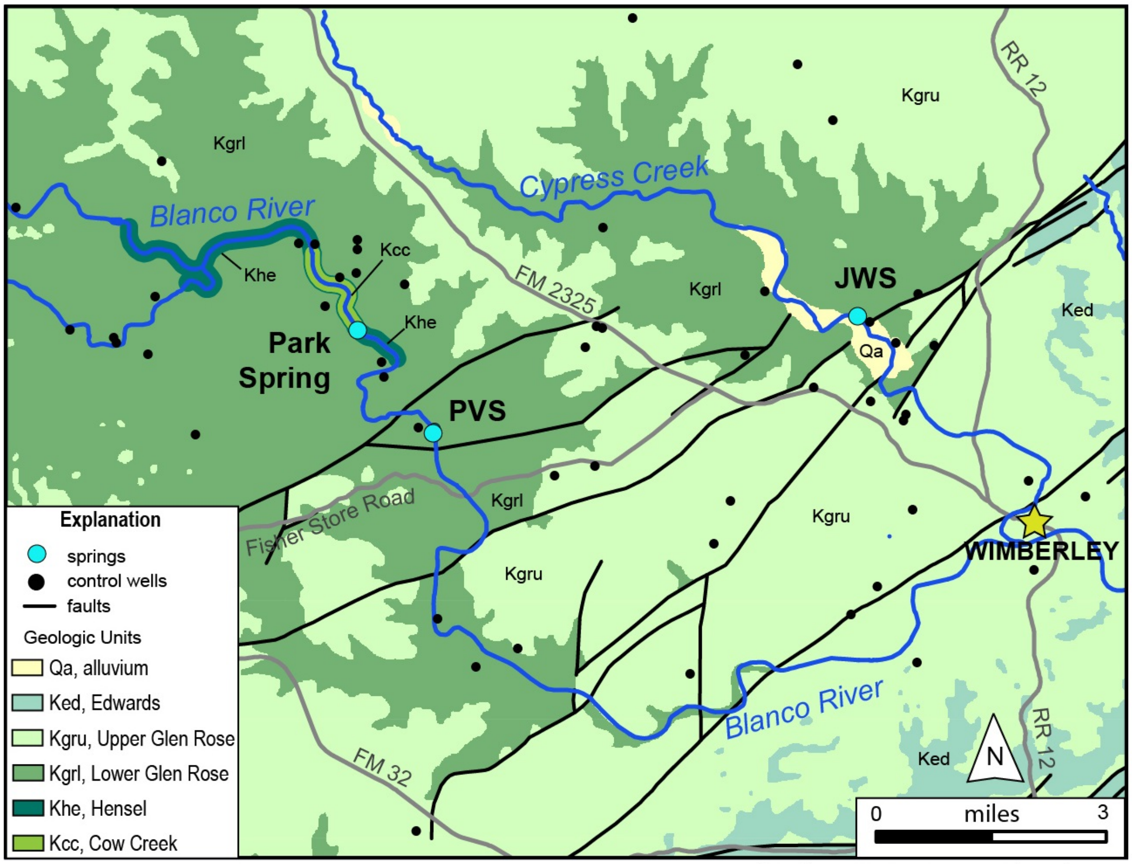

Figure 22: Map of potential Pleasant Valley and Jacob's Well springsheds showing the exposed Lower Glenn Rose outcrops in the vicinity of the two springs.

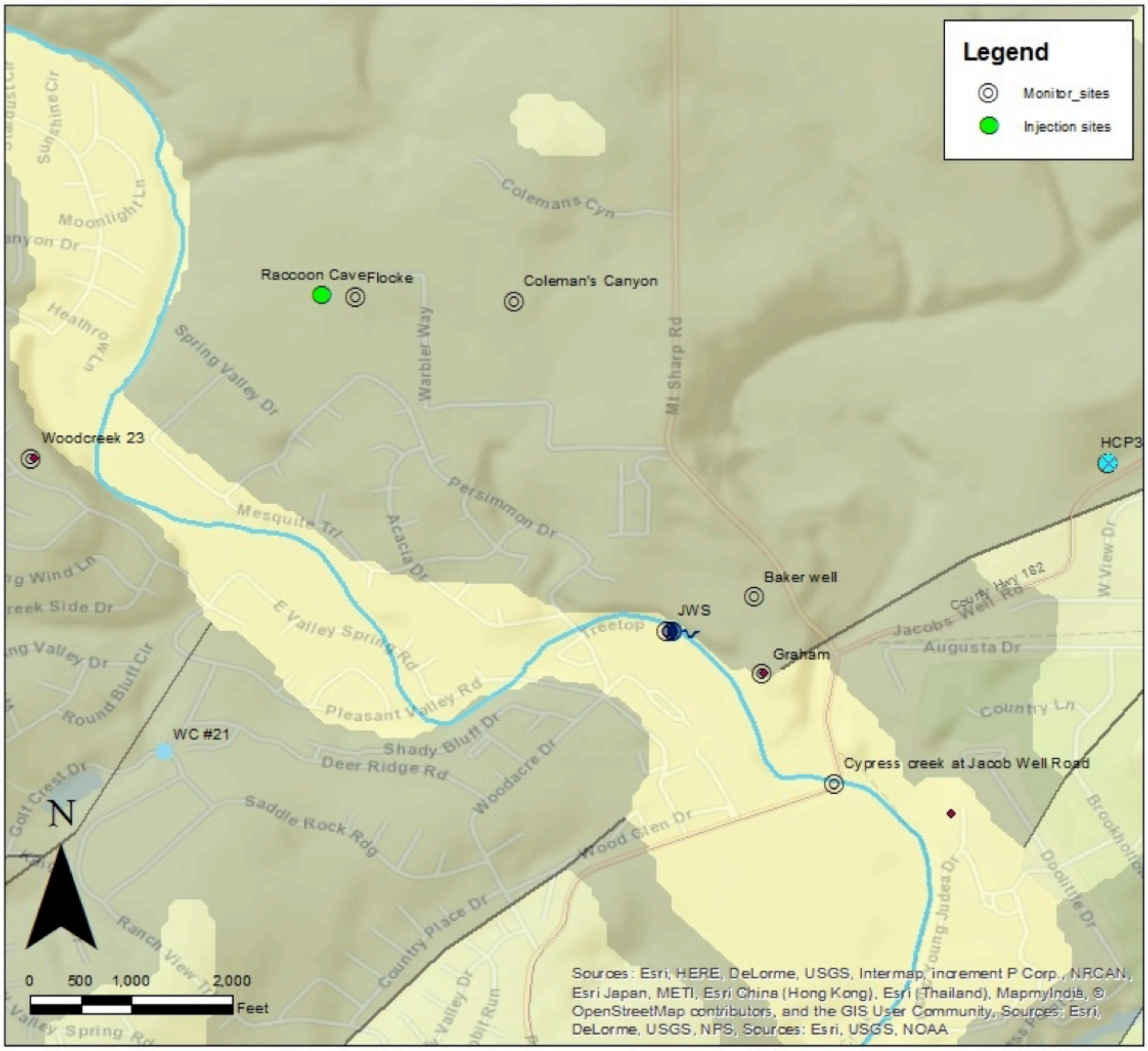

Figure 23: Map for Raccoon Cave Dye Trace Study currently underway. Source: BSEACD.

Depending on the results of future studies, Gary suggested that the watershed could be considered the primary GMZ or zone 1, the area below Tom Creek Fault zone 2, and a 3-5 mile buffer around the watershed zone 3, each with different rules corresponding to their importance to aquifer recharge and springflow.[175] Ultimately, a technical advisory

[175] Gary Interview, 15 Feb, 2018.

committee at HTGCD will draw on these studies as well as other stakeholder concerns to determine the most suitable boundaries.

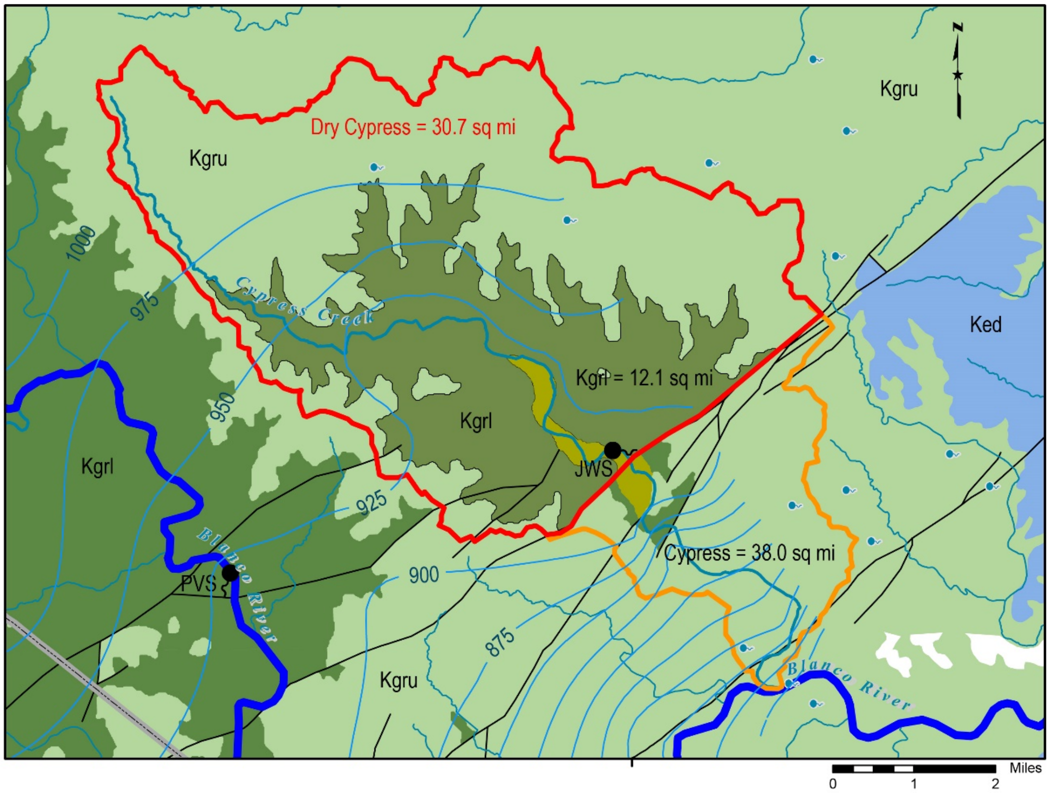

Figure 24: Map of Cypress Creek Watershed in relation to Lower Glenn Rose outcrop surrounding Jacob's Well Spring.

5.1.3 Regional Coordination, Science, and Monitoring (Mitigating Drought, Climate Change, and Increased Demand)

In order to be effective, a Jacob's Well-Cypress Creek GMZ and other potential GMZs in HTGCD should be integrated with monitoring and scientific study as with BSEACD's approach. HTGCD is constructing four additional monitor wells to expand its network. In conjunction with BSEACD's commitment to drill new monitor wells and conduct further study in their newly annexed jurisdiction in Hays County, the comprehensive information about aquifer conditions necessary to defining zones in a sound data-driven manner should facilitate the process and help establish GMZs that will be effective at preserving environmental flows and conserving groundwater for sustainable use. These steps represent an emerging regional coordination of hyper-localized management, per Dupnik's recommendation of building out the DFC monitoring network. Collaboration and coordination with entities such as BSEACD and EEA will be important to keep improving scientific understanding of groundwater flows and availability; further collaborative studies like the ones mentioned above lend HTGCD the ability to strengthen authority with existing resources and defensible scientific data. BSEACD installed two monitor wells in early 2017 in areas "with the highest demand for Trinity water" and are currently studying the potential for dewatering these pumping hot spots. The data from these new wells will inform the revision of the numerical groundwater model for the Trinity Aquifer TWDB will undertake in the few years.[176] Those improved models will be key to determining a sustainable yield for the Hill Country Trinity Aquifer, which could inform setting a lower DFC for the Middle Trinity Aquifer. A more conservative DFC for the Trinity across the entire GMA 9 region would relieve pressure from areas already subject to depletion making for more effective GMZs and encourage a coordinated system of zones across the GMA.

Building on these efforts by establishing a GMZ in collaboration with watershed protection plan implementation has greater potential for more effective drought and climate change mitigation. Locally tailored management combined with regional coordination will increase the effectiveness of hydrologically connected aquifers,

[176] Barton Springs Edwards Aquifer Conservation District, *30 Years*, 4-8.

watersheds, and springsheds. The more these connections (and disconnections) are understood, the more likely that an integrated GMZ approach will be effective at maintaining environmental flows as it will clarify where pumping must cease during drought in order to preserve springflows and that provide instream flows for Cypress Creek. Watershed protection planning currently underway in the Hill Country, for example in the Blanco and San Marcos watersheds, provides further opportunities to coordinate conservation measures to meet water quality goals by making sure there is enough water flowing to keep these rivers, creeks, and springs ecologically healthy. Preserving adequate instream flows keeps riparian ecosystems thriving, which in turn prevents groundwater loss and degradation through evaporation, rapid runoff, and bank erosion. Thriving riparian vegetation stabilizes banks and mitigates the effects of drought and flood in what will hopefully become a self-sustaining cycle of mutually reinforcing protection measures.

5.1.4 Environmental and Economic Resilience Work in Tandem and Reinforce the "Education Piece"

GDEs like the Wimberley Valley are especially important to protect, because they provide ecosystem services that help further protect the baseflows—water quantity that ensures water quality—and environmental flows that support healthy ecosystems and riparian biodiversity. These interrelated ecosystems and interconnected hydrogeology underscore the need for regional coordination in GMA 9 and across Edwards Plateau, a region rich in ecosystems highly dependent on groundwater. Endangered Species litigation could become a significant concern for HTGCD in the near future even if the Fernbank Salamanders present in Jacob's Well are never successfully listed as endangered. The City of Austin Watershed Protection Department just released a report confirming discovery of Barton Springs Salamanders in springs located along Onion Creek within HTGCD's boundaries.[177] Interconnections between the two aquifers and the springs they support suggest the need to broaden the geography in which conservation policies for these endangered species apply.[178] Greater protections for the contributing zone outside of EAA's and BSEACD's boundaries will increase the need for regional coordination of more robust localized groundwater conservation, and GMZs could provide the most effective avenue for doing so.

Environmental resilience means economic resilience, not just tourism, tax revenue, and property values but the ecosystem services for the region (for example, drought mitigation, clean drinking water, cleaner air and carbon sequestration); also continued sustainable growth by maintaining natural amenities people that attracts visitors and residents, and the water needed to support commercial, agricultural, and industrial enterprises including energy production. Stronger groundwater regulations will force demand reduction and hopefully push sustainable development out of economic motive and necessity. As effective education and outreach efforts with proven track records in the urban centers of Austin and San Antonio will inevitably make their way into threatened areas of the Hill Country such as Hays County. Ideally, it will become clearer exactly why development patterns that rely on high consumption of groundwater is no longer feasible as long-time residents and newcomers unfamiliar with geology and hydrology become aware and informed consumers and voters, a more educated public key to eventually making more significant reforms at the legislature.

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[177] Devitt and Nissen, "New Occurrence," 297-301.
[178] *Id.*, 300.

5.2 Potential Pitfalls and Roadblocks for Establishing GMZs in HTGCD

Each of the GCD managers and geologists interviewed were asked to identify potential roadblocks to creating effective GMZs in general and with specific respect to HTGCD. Several themes emerged across the replies and they are summarized here.

5.2.1 Economic and Human Resources

The potential lack of funding for HTGCD could pose a major obstacle to the feasibility of establishing even one GMZ let alone several. Those funds may be necessary to conduct further scientific study to define GMZ boundaries, develop more accurate localized modeling, refine the Drought Trigger Methodology, and analyze data collected from monitoring. Adequate funding will also be necessary to develop and disseminate outreach and education materials to communicate effectively with the public about the process. If the necessary resources for assembling the technical advisory committee and carrying out the rule making processes are not within the District's budget, designating a GMZ may not be a practical undertaking for HTGCD.

Most interviewees also brought up staff and Board capacity as a possible hindrance to spearheading the process, seeing it to fruition, and especially enforcing the rules once they are in place. Without a champion to catalyze and shepherd the process, the District may lack the political will and committed coordination to form the initial committees, do the necessary work, engage relevant parties, and finally promulgate effective rules. Even with all of those potentially arduous tasks completed, enforcement of the rules may prove quite difficult for HTGCD with so few fulltime staff. Such difficulty could be compounded if multiple GMZs were created.

5.2.2 Public Perception and Politics

All of the interviewees emphasized the importance of effective communications in the form of outreach to affected parties and general education of the public about the issues at hand including the need for the rule changes. Hunt recommended bringing the big water producers in the GMZ area to the table early on in the process. He added that the District would likely need to create incentives for those nonexempt permit holders to accept GMZ rules that include pumping limitations.[179] Tybor pointed out that framing HCUWCD's management-zone rules as a way to protect historical users was an effective way to approach and work with the stakeholders inside the HHUAs.[180] Gary stressed the need to get the beneficiaries on board with the idea by framing the rule change as a way to protect exempt domestic wells; he cited the Electro-Purification case as a prime example albeit a slightly different context.[181] Exempt well owners were happy to be free of GCD regulation until a large commercial water producer moved into an unregulated area of Hays County threatening to dry up residents' wells. Those mostly domestic well owners, motivated by loss of their own groundwater property rights, organized to lobby the legislature to become part of BSEACD. They succeeded in getting legislation passed to do so, no simple feat at the Texas Legislature. That same power of public outcry could be turned against GMZ rules without effective outreach.

Public awareness and education will also be crucial to garner wider support for rules that would require reductions in groundwater production. It is notoriously difficult to maintain awareness about the scarcity of groundwater in non-drought years. Communicating effectively about the need to be prepared for the inevitability of drought with clear accessible messages is key. Education and outreach together encourage a more

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179 Hunt, interview by the author.
180 Tybor, interview by the author.
181 Gary, interview by the author.

educated constituency and possibly voters more motivated to make it to the polls for local elections in support of conservation efforts. Without that awareness and support, the GCD or particular board members risk political backlash from constituents, which could mean champions of the GMZ could find themselves voted out of office potentially derailing the rule making process. Last but not least, legislative changes weakening Chapter 36 or the specific management zone subsection could render the hard work of establishing a GMZ moot.

These potential problems and obstacles will be addressed in the following chapter as they inform the recommendations proposed for HTGCD and more generally for GCDs seeking to institute effective GMZs.

Chapter 6: Roadmap and Recommendations for Creating Effective GMZ Policies in HTGCD and Beyond

Because this report's aim is to evaluate the effectiveness of GMZs based on existing management zones and to determine whether they will be effective for HTGCD, this chapter offers a roadmap and recommendations specific to HTGCD in hope that the District can create the most effective GMZs possible. The roadmap is included in recognition that the process itself can be equally important as the resulting regulatory system. Legislative changes follow the recommendations not because they are of less import but because they typically take more time and effort to achieve than local GCD processes.

6.1 Roadmap Overview For HTGCD Creating a Jacob's Well Groundwater Management Zone

The first phase of the Jacob's Well GMZ process will begin with a Board Member champion calling for an action item on the agenda to establish a subcommittee with the District Manager to study and report findings back to the full board. Once formed by a majority vote from the Board, that committee will be tasked with tasks including but not limited to:

1. Meeting with staff and technical advisors active in studying the area to seek guidance and discuss possible collaboration with BSEACD to help develop GMZs for HTGCD or help build staff and Board capacity for doing so.
2. Forming technical advisory subcommittee to help identify the appropriate boundaries based on past watershed and forthcoming springshed studies including dye trace testing.

3. Reaching out to large producers with existing permits with incentives to support GMZ rules, possibly relocating existing municipal supply wells, or retiring permitted groundwater not currently being pumped.
4. Reaching out to beneficiaries, i.e. exempt domestic well owners, to garner public support as the more stringent rules will protect their historical use.
5. Identifying what further data and additional participants will be needed to move forward.
6. Determining scope, feasibility, budget, and timeline for completing the process to determine if practical. Reporting back to Board.

The second phase will involve the committee and stakeholders reviewing the initial findings in order to develop provisional rules that define management within the GMZ, which could include but are not limited to:

1. Setting permit conditions, caps on permit amounts, distinct curtailment schedules for drought triggers, and types of permits allowed within the zone. In other words, drafting the rule changes.
2. Creating a localized GAM to capture accurate groundwater availability in the management zone. *(Optional but included in HTGCD's Management Plan)*
3. Developing an official DFC for the specific area that can respond to the aquifer depletion. *(Optional but included in HTGCD's Management Plan)*
4. Continuing outreach and education efforts.
5. Present final report presentation to the full Board and public for consideration.

6. Holding required public hearing on draft of GMZ recommendations after adequate public comment period.
7. Making any necessary revisions to the new rules.
8. Placing on the Board Meeting Agenda as action item to adopt GMZ rules and voting to revise or adopt GMZ.

Assuming passage of the GMZ rules, the third phase will involve implementation, planning, and education including but not limited to:

1. Amending Rules and Bylaws to reflect rule changes.
2. Updating Management Plan to reflect rule changes and related strategies.
3. Crafting an enforcement plan and carrying it out as needed.
4. Continuing scientific study and monitoring to refine rules and parameters to meet the GMZ goals of maintaining springflow at Jacob's Well.
5. Developing more simple indictors and messaging for continued public awareness and education.
6. Conducting further study to determine which other areas of the District need stronger protection from depletion and which may be less threatened and allow for more groundwater production.
7. Submitting GMZ-specific DFCs to GMA for approval and inclusion in regional and state plans.

Many of the phase three activities will continue as part of the Districts' adaptive management and public education efforts.

6.2 Improving GMZ Approach and Other Recommendations

6.2.1 Recommendations for Establishing Effective Groundwater Management Zones in HTGCD and Elsewhere in the State

The first set of recommendations addresses limited economic resources for scientific study and other costs associated with the public process including website improvements as well as other education and outreach materials.

Short Term:

- The District should increase its spending to meet the needs of this project; the 2017 budget was only 50% and actual spending only 60% of HTGCD's 2017 annual income.[182]
- The most effective short term strategy other than increased spending will be to collaborate with willing partners already engaged in scientific study and groundwater monitoring including BSEACD, EAA, and Meadows Center for Water and the Environment staff, as well as working local NGOs, government stakeholders and community volunteers involved in Watershed Protection Plan implementation to draw on already existing resources and experienced, knowledgeable individuals.

Longer Term:

- Although the District collected $577,000 in 2017 from well registration and connection fees due largely to rapid population growth, they should still consider a legislative amendment to enabling legislation to grant District authority to charge for groundwater. As noted earlier, BSEACD charges production fees of $0.17/1000gallons in the Middle Trinity GMZ. If HTGCD were able to charge that rate to its "Top 15 Users" in 2016,

[182] Hays Trinity Groundwater Conservation District, *2017 Annual*.

they would have collected $83,553 in fees.[183] If it were able to charge that fee for all groundwater pumped in 2017, the District would have collected $100,541 increasing their income by nearly 20%.[184] Although perhaps even more politically difficult passing a legislative amendment allowing the District to collect an ad valorem tax might be more effective. If GMZ curtailments and other permitting restrictions associated with the GMZ led to fewer connections and less groundwater production, HTGCD could lose a significant amount of revenue.

The next set of recommendations addresses limited staff and Board capacity to spearhead the rule change, shepherd process, enforce the rules once in place as well as conduct education and outreach to affected constituents, other stakeholders, and the general public.

- Human resources for outreach to affected parties and other stakeholders could be addressed by working with consultants and facilitators with experience in mediating water-related conflicts to develop win-win scenarios for the District and their constituents. Other trusted messengers in the community such as public officials, prominent citizens, and area business leaders could also play important roles in communicating the advantages of establishing a GMZ.
- The District should consider hiring additional human resources for education and public awareness campaign. A staff member or contracted

[183] Hays Trinity Groundwater Conservation District, Top Users, 1.
[184] Hays Trinity Groundwater Conservation District, *2017 Annual*.

public relations consultant could help develop an effective campaign in the short term. Existing staff should also draw on the resources, experience, and knowledge of the volunteer stakeholders and experts involved in the Cypress Creek Watershed Protection Plan to educate residents about alternatives to using groundwater, for example harvesting rainwater for non-potable uses like flushing toilets and watering landscapes. Drawing on successful campaigns like those proven successful in the City of San Antonio could also help grow support for the GMZ while simultaneously reducing demand.

- The best way to guard against limited human and economic resources for enforcement would be to hire regulatory compliance staff. BSEACD has two Regulatory Compliance Coordinators and one Regulatory Compliance Specialist on their staff. HTGCD should consult with its neighbor GCD to determine what skills and background are needed and how much time monitoring compliance and taking enforcement action requires. They could also consider contracting a 3rd to party if it proved more cost-effective with just one GMZ in place at the outset.

These recommendations address the pitfalls of not engaging in effective outreach to affected parties and other stakeholders in the District.

- Engaging large groundwater producers early on in the process to help develop incentives that would secure their support. Again drawing on the experiences and knowledge of stakeholders from both civic and private sectors involved in local watershed protection planning may provide an expedient and less controversial way to develop incentives. If these incentives require more financial resources than available, the District should seek to find NGOs and other institutions, which might be willing to help raise funds if necessary.

- Framing rules as protection for existing users (exempt domestic well owners) to get support of immediate beneficiaries of the GMZ rules. Using self-interest as a motivator can prove effective to garnering support as was the case HCUWCD’s HHUAs. If the aquifer is not sufficiently protected and municipal supply wells in the area are impacted, water rates could climb. A GMZ could provide some protection from rate hikes.

These recommendations address the pitfalls of not engaging in effective education and public awareness campaigns. The efforts below could be coordinated with Cypress Creek Watershed Protection Plan education and outreach efforts and supported by local volunteers and college internships. These measures will be important for electorate support of the Board’s GMZ champion and supporters and general awareness of the need for conservation vital to stepping up voluntary conservation measures.

- The District should revive their currently moribund online/email newsletter active in 2009-2010.
- A simpler and more visually attractive drought indicator interface could be developed following best practices of professional environmental educators.
- Issuing regular communiqués via Hays County newspapers (paper and digital), radio stations, online videos, and social media would raise the profile of HTGCD and keep communities apprised of the important work that they do.

This section contrasts the advantages of BSEACD's and HCUWCD's very different management zone approaches to highlight some options from each and to prompt further discussion of how HTGCD might undertake a hybrid or wholly novel approach to establishing GMZ rules. Other than the length of the rule making process and amount of scientific study preceding them, the way in which the rules were written by these two GCDs constitutes another major difference between their management zone systems. While BSEACD's management zone strategy includes the entire District and is thus thoroughly integrated into most of its governing rules, HCUWCD wrote their one stand-alone rule (Rule 9) for their HHUA and CGDA system. While mention of those does appear in a few other parts of the rules, overall the system and rules governing it are much simpler than BSEACD's. HTGCD should consider beginning with the simpler more expedient approach to get the rules in place before proceeding to a more ambitious system of GMZs and a fully integrated approach. As mentioned several times above, an integrated regional monitoring and adaptive management strategy for HTGCD would likely provide the most lasting and effective protection of groundwater resources for consumption, recreation, environmental flows, and economic security. Like BSEACD, HTGCD could become yet another model for effective long-term groundwater conservation and spur even more regionally coordinated localized protections.

6.2.2 Feasible Legislative Changes to The Texas Water Code

Although sweeping conservation-oriented regulatory legislative changes are difficult to effect in Texas, some changes may be more feasible in the near- to mid-term that could make significant improvements. Based on conversations with the interviewees, fours such changes emerged over the course of this study.

1. Even modest funding regional GMA water planning would improve the state's water plans by allowing additional time and personnel to carefully develop and study the best available science. Additional resources might also allow for the involvement of more and/or greater expertise including practitioners from outside the state.
2. Refining models to capture aquifer variations will be a tremendous step in the right direction. While groundwater is not as mysterious and occult as once believed, there is still much to learn about the difference between the distinct hydrogeology of smaller areas of many aquifers. The more refined models as well as understanding of groundwater flow patterns and availability at local scales, the better GCDs can protect areas in danger of depletion and can identify areas where plentiful groundwater may exist for production.
3. Expanded monitoring and investing in new technologies to get more accurate inventory of available groundwater. As with the recommendation above, legislative changes that support more science-based policy are not only crucial but also more amenable to legislators. With the sophisticated University system and ever-growing technology sector, developing new innovative technology for water monitoring and measuring should be supported and incentivized by a legislature that prioritizes the state's business-friendly climate and economic development.
4. Explicit protections in Chapter 36 for GCDs against takings claims and other checks on groundwater ownership and rule of capture. If

groundwater is to be treated as private property and yet subject to *some* regulation, clearer boundaries need to be articulated about the extent to which private property rights take precedent over regulatory actions. Give their conservation mission, GCDs should be provided explicit protections from takings claims in the management zone subsection and perhaps other sections of Chapter 36. Exempting management zone rules from the Rule of Capture regime would strengthen the provision and encourage more GCDs to create and use them more effectively.

6.3 CONCLUSION

The state of Texas truly needs major legislative reforms to move away from the bifurcated management of groundwater and surface water, to abandon the Rule of Capture, and to adopt more integrated, conjunctive water management across the state. Until that kind of legislative action occurs, water planners and managers will continue struggling to ensure ample water supply for the millions of new Texans projected to move here in the next thirty years as well as the industries and thriving economy needed to support them. In the meantime, GCDs must use the tools currently at their disposal to protect groundwater where it is most threatened. This report has examined one such tool, the Groundwater Management Zone, and focused on one tiny area of this very large state to illustrate what can be done in the near term. While one GMZ at such a small scale will hardly solve the larger statewide systemic problems, it can illuminate a way forward that has the potential to draw more attention to one of the most pressing issues of our time. Just as Texas is a bellwether state the challenges of attaining resiliency in the face of climate change and population growth, the Wimberley Valley and HTGCD are the bellwether for the Hill Country region. An effective, well-conceived GMZ for HTGCD can provide a replicable model for conserving groundwater in the region and other areas of the state facing similar threats.

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